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Research paper

Causes and analysis of position offset of curvilinear continuous beam bridge

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Abstract: This study investigates the problem of beam deflection in curved continuous beam bridges. Taking the D0–D6 spans of the Gongbin Road viaduct as a basis, the main factors influencing the deflection of curved beam bridges are analyzed. The Midas/Civil finite element simulation software is used to calculate and analyze the causes of transverse and longitudinal deflection in curved beam bridges. The results show that the main influencing factor for beam deflection during operation is the system temperature, which causes a displacement greater than the combined displacement caused by self-weight, construction stage, gradient load, vehicle load, and bearing settlement. Damages to expansion joints during operation change the boundary conditions of the beam, preventing longitudinal free expansion under temperature load, and increasing the transverse displacement to 2–3 times the normal working state of the expansion joint, resulting in beam deflection. In the design phase, the selection of curvature radius and fixed support displacement is also a major factor affecting deflection. The smaller the curvature radius, the greater the influence on transverse and longitudinal deflection of the beam. However, when the curvature radius R is greater than 400 m, the impact on beam deflection can be neglected. The closer the fixed support position is to the ends of the bridge, the higher the possibility of bearing detachment, ultimately leading to beam deflection.

Keywords: continuous beam bridge, deflection, simulation analysis

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1. Introduction

With the rapid economic development and constant technological advancements, the transportation industry in China as entered a new era, particularly in the field of highway bridge development, has made remarkable achievements. Due to their large quantity and significance, the daily maintenance and repair work of these bridges deserve more attention [1–3]. Due to the fact that many of these bridges were constructed in the previous century and were limited by the technology available at that time, the design load standards and capacity to accommodate traffic are unable to meet the current demands [4]. Currently, the funding for highway bridge construction in China is primarily allocated to the construction of large-scale bridges, while limited funds are available for medium and small span bridges. For those medium and small bridges that cannot meet the current traffic demands due to their scale, it is almost impossible to demolish and rebuild them. Instead, they require renovation to meet the current traffic requirements [5, 6].

In order to better renovate medium and small span bridges and serve the people more effectively, it is crucial to address the common structural issues that these bridges face. However, there is still insufficient attention given to these structural problems. One such issue is the displacement of the superstructure, which significantly affects the normal usage of the bridges. Among them, medium and small span curved continuous girder bridges are more prone to superstructure displacement due to their complex structure and load-bearing characteristics, especially under the long-term effects of various loads [7–9]. Analyzing the causes of bridge displacement, a common problem, is of significant importance in improving the efficiency of addressing this structural issue and reducing the occurrence of such problems in medium and small span bridges in China. Ensuring the safety of bridges during their operational phase holds great significance [10, 11].

2. Engineering background introduction

The Gongbin Road elevated bridge system is located in Harbin, Heilongjiang Province, China, and is designed for City-A class load rating [12]. The mainline section of the Gongbin Road elevated bridge system consists of 119 spans. This study focuses on the analysis of displacements in spans D0–D6. The superstructure of spans D0–D6 is a continuous reinforced concrete curved-box beam with six spans. The span combination is $20+4\times25+20 = 140$ m, and the box beam consists of two boxes with six chambers. The height of the box beam is 1.4 m. The total width of the D0–D6 span bridge deck is 28 m, and the bridge width is arranged as follows: 0.5 m crash barrier +12.0 m roadway +2.0 m median divider +12.0 m roadway +0.5 m crash barrier. The substructure of pier D1–D5# consists of column-type piers, while pier D6 adopts a prestressed concrete inverted T-shaped cap beam pile-pier structure, and the abutment is a reinforced concrete rectangular abutment. The actual scene of the elevated bridge is shown in Fig. 1. The elevation, plan, and cross-sectional views of the bridge are shown in Fig. 2 to Fig. 4.

Fig. 1. Aerial view of the elevated bridge

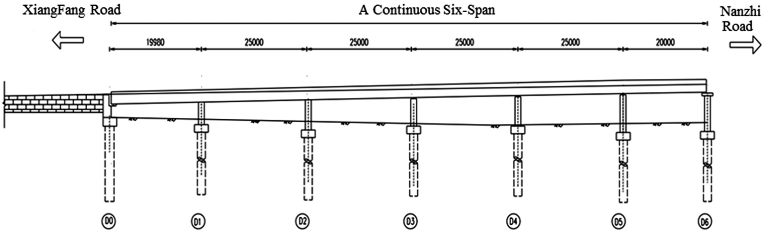

Fig. 2. Bridge elevation layout diagram (unite: mm)

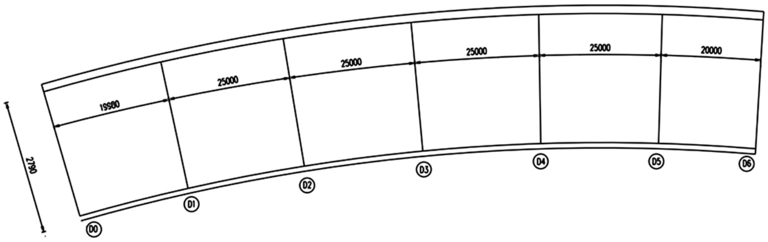

Fig. 3. Plan layout diagram (unite: mm)

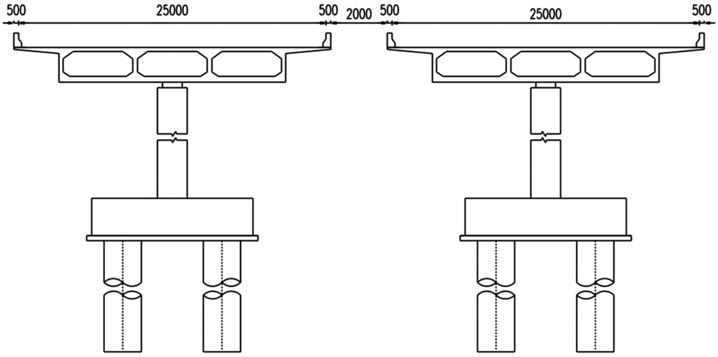

Fig. 4. Cross-section layout diagram (unite: mm)

3. Displacement defects

1. During inspections, it was found that the main beams of the curved continuous beam bridge showed clear signs of lateral displacement towards the outside of the curve. The displacement was most pronounced at pier D6, with a lateral displacement measurement of at least 90 mm at the abutment block on the outer side of the curve. This lateral displacement of the continuous box beams has resulted in severe structural defects in the lower bearings, pier columns, and even the adjacent ramp bridges. At the end section of the cap beam of pier 6 (on the outer side of the curve), the abutment block has fractured due to lateral compression from the main beams, posing a risk of falling, as shown in Fig. 5.

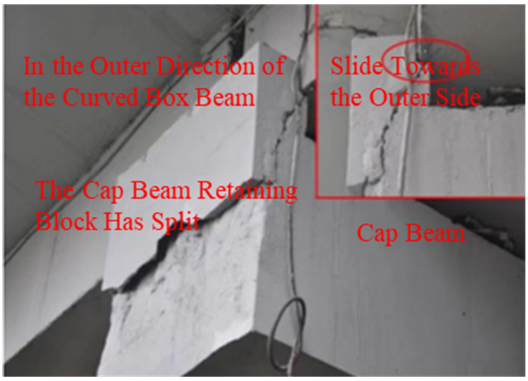

Fig. 5. Diagonal splitting of bridge abutment cap beam block

2. In some cases, there is a displacement of 40 mm between the upper steel plates and the steel pots, as shown in Fig. 6 and Fig. 7. The lateral displacement of the curved beam bridge causes the upper steel plates on the bearings to move along with it. Inspections have revealed a common occurrence of outward sliding of the upper steel plates in

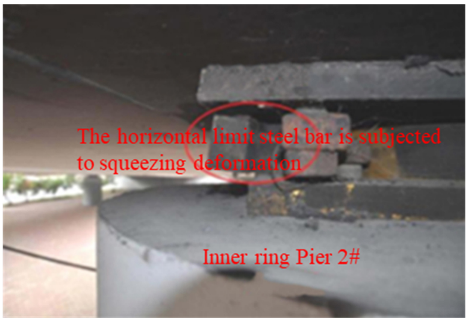

Fig. 6. Compression deformation of lateral restraining steel bar

Fig. 7. Sliding of upper steel plate out of steel basin by 40 mm

bi-directional movable bearings. Careful measurements of the lateral displacement of the under-pot elastomeric bearings for spans D0 to D6 of the continuous box beams were conducted, with the measurement locations illustrated in Fig. 8.

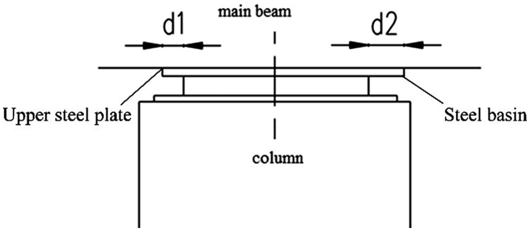

Fig. 8. Schematic diagram of displacement measurement for pot rubber bearing with upper steel plate

According to Table 1, both the steel plate on the unidirectional and bidirectional pot-type rubber bearings shift outward. Fixed bearings have no lateral displacement, which is determined by the bearing type. The lateral displacement of the steel plate on the bidirectional bearings is greater than that of the unidirectional bearings due to the presence of limit steel plates in the transverse direction of the bridge.

Table 1. Lateral displacement of pot rubber bearing

Bearing number	Bearing type	d1 (mm)	d2 (mm)	Lateral displacement of the bearing (d2 – d1)/2 (mm)
Outer ring D1# pier	Bidirectional	32	43	5
Inner ring D1# pier	Unidirectional	46	46	0
Outer ring D2# pier	Bidirectional	20	62	21
Inner ring D2# pier	Unidirectional	40	60	10
Outer ring D3# pier	Unidirectional	42	70	14
Inner ring D3# pier	Fixed	–	–	–
Outer ring D4# pier	Bidirectional	–10	84	47
Inner ring D4# pier	Unidirectional	18	87	34
outer ring D5# pier	bidirectional	–25	105	65
Inner ring D5# pier	Unidirectional	47	61	7

3. The lower outer side of the bridge pier column is characterized by multiple semi-circular cracks, as shown in Fig. 9. The maximum width of the cracks is 0.26 mm, and the crack distribution is illustrated in Fig. 10. The analysis suggests that the presence of fixed pot-type bearings on top of the pier is the reason behind this. The lateral displacement trend of the main beam is constrained by the fixed bearings. According to the principle of force interaction, the main beam exerts a radial force on the bearings in the direction of displacement. This causes a transition in the compressive state of the bridge pier column from axial compression to eccentric compression, leading to tensile stress in the concrete on the outer side.

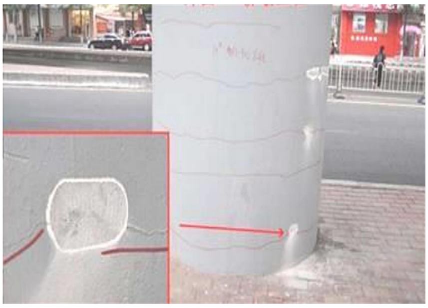

Fig. 9. Bottom half-ring crack in bridge pier concrete

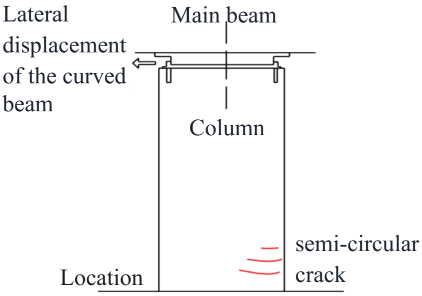

Fig. 10. Schematic diagram of crack in bridge pier column

4. Causes of misalignment in curved continuous beam bridges

The misalignment of bridges is commonly observed during both the construction and operation phases. Taking into account various factors, the causes of bridge misalignment during its service life can be broadly classified into two categories: intrinsic structural factors and external environmental influences [13]. Intrinsic structural factors refer to the choice of alignment, beam section configuration, bearing type and distribution, pier type and height, selection of bridge structure type, etc. External environmental factors include temperature variations (seasonal and diurnal temperature differences), traffic volume (overloaded vehicles and peak-hour traffic, etc.), and occurrences of incidental events (earthquakes, typhoons, vehicle and vessel collisions, etc.).

1. Inherent factors of curved beam bridge
   Under external loading, curved beam bridges exhibit significant bending and torsional coupling effects, resulting in larger deformations compared to straight bridges of the same span. Fig. 11 shows the generation of torque in a curved beam bridge, and when subjected to additional loads from vehicles and temperature effects, the deformations are further amplified. Through research and analysis, it has been found that the coupling effects of bending and torsion change with decreasing curvature radius. Smaller curvature radii lead to greater coupling effects, making the bridge more prone to misalignment issues under external loading. Curved beam bridges not only experience longitudinal misalignment problems but also exhibit transverse misalignment. This results in the bi-directional sliding of the bridge, where the transverse displacement interacts with the longitudinal displacement, further enhancing the occurrence of misalignment.
2. Traffic and vehicle effects
   The actions of vehicle loads during motion, including the effects of gravity and centrifugal forces, will cause a tendency for the curved beam bridge to move outward from the arc. This movement can result in shear damage to expansion joints and

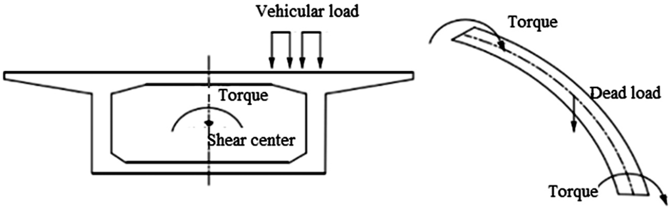

Fig. 11. Diagram of torque generation in curved beam bridge

bearings of the bridge [14]. The magnitude of centrifugal force is determined by the speed of vehicles traversing the bridge deck and the curvature radius of the bridge itself. The smaller the radius of curvature and the higher the speed of vehicle travel, the greater the centrifugal force.

3. Unreasonable support arrangement
   For curved beam bridges, the selection of fixed bearing locations affects the degree of pier settlement. The closer the ends are to the supports, the more likely it is to experience bearing uplift phenomena. Under external loading, the deformation and reaction forces of the supports cause beam deflection and torsion. The occurrence of accidents can be greatly reduced through proper bearing arrangement.
4. Effects of temperature and shrinkage creep
   After being put into use, bridges are affected by temperature differential loads caused by solar radiation and seasonal temperature changes. Solar radiation leads to temperature differentials across the beam section, while seasonal temperature changes cause the beam to undergo expansion and contraction deformation [15, 16]. This can cause different levels of deformation or bearing diseases in bridges, making the beam deflect under the influence of induced secondary stresses, as shown in Fig. 12 to Fig. 13. Extensive studies have shown that the deflections caused by temperature loads are much larger than the effects of shrinkage creep. Additionally, under normal circumstances, deflections induced by temperature loads are the largest. Therefore, research on the effects of temperature loads is of utmost importance in preventing and treating deflections.

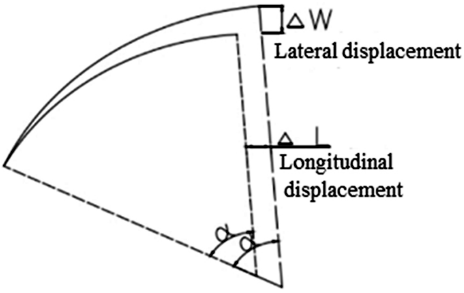

Fig. 12. Schematic illustration of seasonal temperature effects on beam displacement

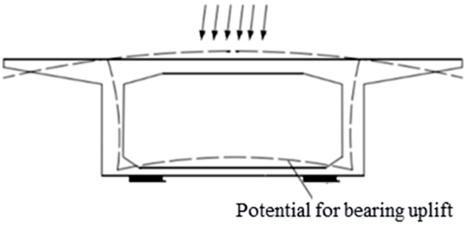

Fig. 13. Schematic illustration of solar radiation temperature difference effects on bearing

5. The influence of the radius of curvature
   In the design of curved beam bridges, the selection of the radius of curvature plays a significant role. When the span is fixed, as the radius of curvature gradually increases, the influence on the lateral displacement of the beam decreases, showing a nonlinear reduction. When reaching a certain value, compared to other influencing factors, it can be considered negligible [17]. Therefore, it is important to exercise caution when selecting the radius of curvature for small-radius curved beam bridges. The centrifugal force generated by the curvature also has a significant influence on the longitudinal displacement of the bridge. Before reaching a certain value of the radius of curvature, the centrifugal force has a substantial impact on the lateral displacement of the beam. Hence, the selection of the radius of curvature for curved beam bridges should be made after comprehensive consideration.
6. The influence of other factors
   The causes of bridge displacement are numerous and complex. In addition to the aforementioned reasons, some incidental factors may also trigger bridge displacement, such as inaccurate or incomplete route information collection during the design phase. Moreover, during construction, beam displacement may occur due to various unforeseen risks.

5. Simulation analysis of lateral displacement in curved continuous beam bridge

5.1. Establishing a finite element model

This paper establishes a finite element model using finite element software to analyze the factors affecting lateral displacement in curved continuous beam bridges. The analysis primarily focuses on the influences of self-weight load, bridge deck pavement and guardrails (constant load in phase two), system temperature load, temperature gradient load, vehicle load, support settlement, and stuck expansion joint, among others. It also examines the degrees of influence on beam displacement caused by different temperatures, different support distributions, different curvature radii, and stuck expansion joints. This study aims to provide reasonable solutions for future handling of bridge displacement issues. The vehicle load is Class I vehicle load on the highway, refer to the code for design of the municipal bridge. The system temperature increase is considered as 20°, and the system temperature decrease is considered as 30°. The temperature gradient decrease is considered as 8.5°, and the temperature gradient increase is considered as 8.5°.

Based on the construction drawings of the Gongbin Road elevated bridge for spans D0 to D6, a modeling was conducted using MIDAS/Civil software. According to the requirements of section variation characteristics and support point placement, the model consists of 164 nodes and 155 elements, as shown in Fig. 14. General support is adopted between continuous beam and pier. A fixed support is provided, and the rest are unidirectional and multi-directional movable supports.

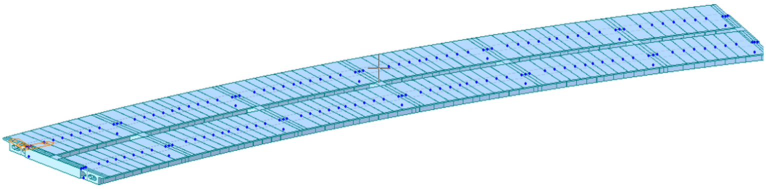

Fig. 14. Model structural rendering

5.2. Degrees of influence of each factor causing displacement

In order to better address bridge displacement issues, it is important to not only understand the causes of bridge displacement but also to assess the degrees of influence that each factor has on bridge displacement. The focus is on analyzing the influence of structural self-weight, phase two loads (bridge deck pavement and guardrails), temperature gradient and system temperature, vehicle load, and support settlement on the lateral and longitudinal displacements of the bridge.

The structure is a symmetrical structure, and 0# abutment, Pier 1, Pier 2, and Pier 3 are selected as the research objects. The deformation induced by bridge displacement factors is shown in Fig. 15. The longitudinal deformation caused by bridge displacement factors is shown in Fig. 16.

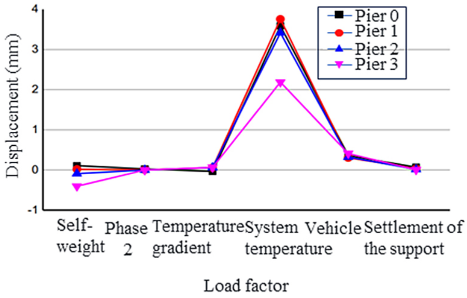

Fig. 15. Lateral displacements of the main beam at various locations

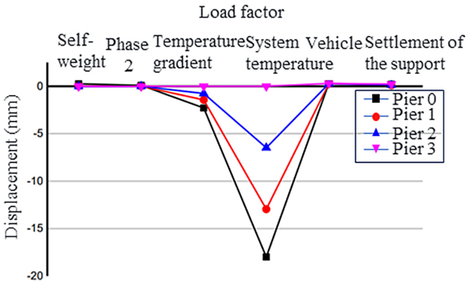

Fig. 16. Longitudinal displacements of main beam at various locations

From Fig. 15, it can be observed that regardless of the location, whether at the beam end or in the middle, under various load conditions, the system temperature load has the greatest influence on bridge lateral displacement. When the overall temperature increases by 20 degrees, the maximum lateral displacement occurs at section 1# and 5# piers, reaching 3.8 mm, which is several times larger than the displacements caused by other loads. The system temperature load is the primary factor causing lateral displacement of the beam.

From Fig. 16, it can be observed that similar to the lateral displacement, regardless of the location, whether at the beam end or in the middle, under various load conditions, the system temperature load has the greatest influence on bridge lateral displacement. When the overall temperature increases by 20 degrees, the maximum lateral displacement occurs at the 0# and 6# pier abutment sections, reaching 18.0 mm, which is several times larger than the displacements caused by other loads. The system temperature load is the primary factor causing longitudinal displacement of the beam.

5.3. Degree of influence of support type on beam displacement

In a curved girder bridge, a fixed support is usually installed to mitigate displacement issues. This study aims to analyze the degree of influence of changing the position of the fixed support on the lateral and longitudinal behavior of the beam. Four different positions of fixed supports are proposed for analysis, as detailed in Table 2 and illustrated in Fig. 17 to Fig. 20.

Table 2. Distribution of fixed supports

Condition	**Fixed support position**
Condition 1	Fixed support located at Abutment 0
Condition 2	Fixed support located at Pier 1
Condition 3	Fixed support located at Pier 2
Condition 4	Fixed support located at Pier 3

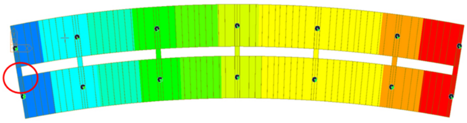

Fig. 17. Fixed support located at Abutment 0

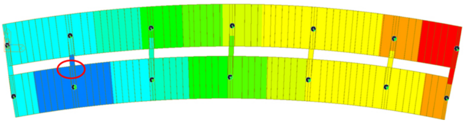

Fig. 18. Fixed support located at Pier 1

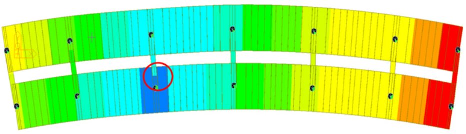

Fig. 19. Fixed support located at Pier 2

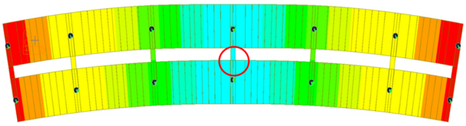

Fig. 20. Fixed support located at Pier 3

Under the four different arrangements of fixed supports mentioned above, the lateral and longitudinal displacements of each support point under temperature load are discussed. The overall temperature rise is considered as 20°. The detailed data of lateral displacements of each support point under temperature load for different fixed support arrangements are presented in Fig. 21. Longitudinal displacement of the main beam under temperature load is shown in Fig. 22.

From Fig. 21, it can be observed that under the influence of temperature load, the closer the fixed support is to the middle position, the smaller the lateral displacement. Therefore, when setting the fixed supports, it is preferable to place them closer to the middle position, which helps prevent lateral displacement. From Fig. 22, it can be seen that under the influence of temperature load, the placement of fixed supports has minimal impact on longitudinal displacement offset.

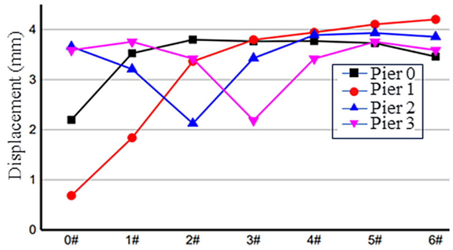

Fig. 21. Comparison of transverse displacement of the main beam under temperature load

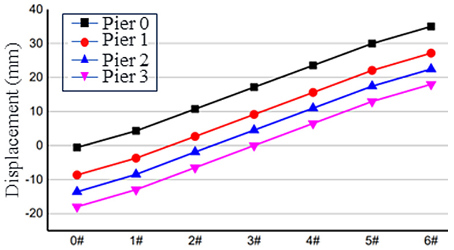

Fig. 22. Longitudinal displacement of the main beam under temperature load

5.4. Degree of influence of temperature load on beam displacement

For the beam subjected to uniform temperature rises of 20°, 25°, 30°, and 35°, under the same bridge span arrangement and constraints, the analysis of longitudinal and lateral displacements of the beam is shown in Fig. 23 to Fig. 24.

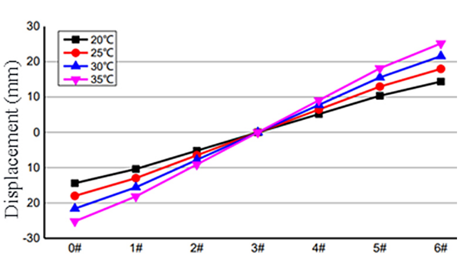

Fig. 23. Comparison of longitudinal displacement of the main beam under overall temperature rise

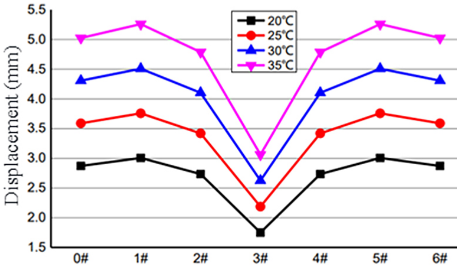

Fig. 24. Comparison of transverse displacement of the main beam under overall temperature rise

Due to the project's location in the northern region where temperatures are lower during the winter season, apart from considering the influence of temperature rise, more emphasis is placed on the effects of temperature reduction. Hence, the analysis of longitudinal and lateral displacements of the beam is conducted under the conditions of overall temperature reduction to –5°, –10°, –15°, and –20°, with the same bridge span arrangement and constraints, as shown in Fig. 25 to Fig. 26.

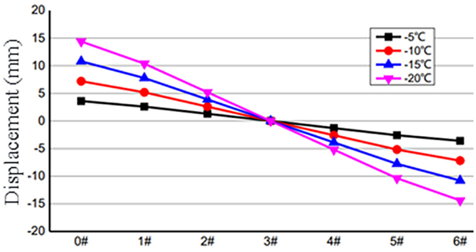

Fig. 25. Comparison of longitudinal displacement of the main beam under overall temperature decrease

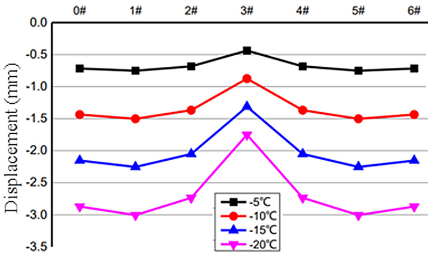

Fig. 26. Comparison of transverse displacement of the main beam under overall temperature rise

According to Fig. 23 and Fig. 24, it can be observed that for curved beam bridges, both overall temperature rise and overall temperature reduction have significant effects not only on the lateral displacement but also on the longitudinal displacement of the bridge. Therefore, when designing curved bridges, it is necessary to consider the influence of seasonal temperature variations on the lateral and longitudinal displacements and select the optimal design solution accordingly.

Bridges inevitably undergo various natural environmental challenges during their service life, which vary with the changing seasons. When the beam is subjected to seasonal temperature rise, according to the principle of thermal expansion, the beam will deflect towards the outer side of the curve segment. Conversely, when the temperature decreases, the beam will contract towards the inner side of the curve segment due to the principle of cold contraction. This process occurs repeatedly over the long term. However, due to the presence of the curved bridge's radius of curvature, when the beam is subjected to external loads, it not only undergoes bending deformation but also experiences torsional deformation due to non-uniform stress distribution. Moreover, most concrete beam bridges are supported by rubber bearings. Under the influence of temperature load and curvature radius, the outer rubber bearings experience a significant amount of compression, while the inner rubber bearings experience less compression.

5.5. The degree of influence of radius of curvature on beam deflection

Comparison of transverse displacement of the main beam under temperature gradient and system temperature is shown in Fig. 27 to Fig. 30. Beam deflection is more likely to occur in curved beam bridges, while the possibility of deflection in straight beam bridges of the same span is relatively small. Therefore, the radius of curvature of the curved beam bridge itself is one of the influencing factors. Different bridges have different radius of curvature, denoted by the numerical value R. The radius of curvature for a straight beam bridge is infinity. This section will discuss the degree of influence on the lateral and longitudinal deflection of the beam under different radius of curvature values. Specifically, we will discuss five different radius of curvature values: $R = 75$ m, $R = 100$ m, $R = 200$ m, $R = 400$ m, and $R = 1000$ m, under the same span and bearing arrangement conditions, and analyze their effects on the lateral and longitudinal displacement of the bridge under different loadings. The system temperature increase is considered as 20°, and the system temperature decrease is considered as 30°. The temperature gradient decrease is considered as 8.5°, and the temperature gradient increase is considered as 8.5 °.

From the above diagram, it can be seen that as the radius of curvature increases, the curve becomes smoother and the lateral displacement under isotropic loading decreases. The rate of decrease in lateral displacement is not linear. The influence of radius of curvature on lateral displacement can be negligible for R >400 m. Therefore, in the design of curved bridges, it is possible to consider controlling partial lateral displacement by reasonably changing the radius of curvature. The overall temperature increase is considered as 20°, and the overall temperature decrease is considered as 30°. The temperature gradient decrease is considered as 8.5 °, and the temperature gradient increase is considered as 8.5°.

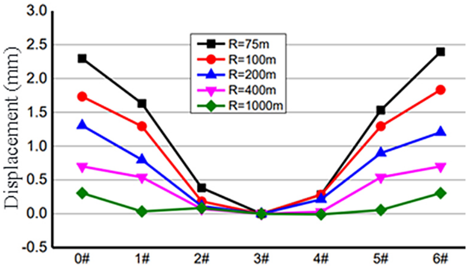

Fig. 27. Comparison of transverse displacement of the main beam under temperature gradient increase

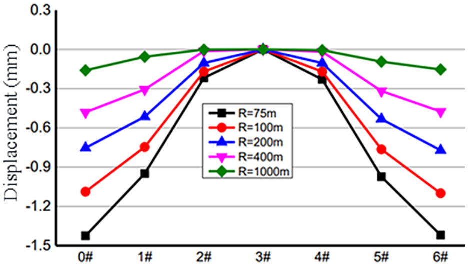

Fig. 28. Comparison of transverse displacement of the main beam under temperature gradient decrease

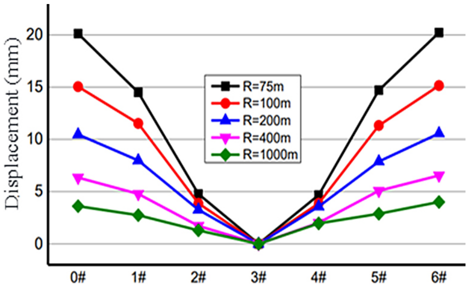

Fig. 29. Comparison of transverse displacement of the main beam under system temperature increase

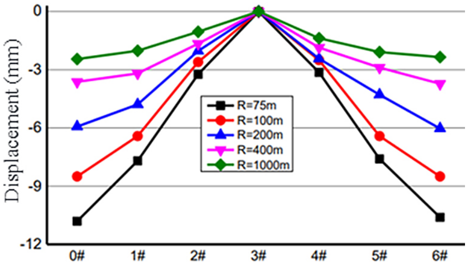

Fig. 30. Comparison of transverse displacement of the main beam under system temperature decrease

Comparison of longitudinal displacement of the main beam under temperature gradient and overall temperature is shown in Fig. 31 to Fig. 34. Different radius of curvature values have a significant impact on the lateral displacement of the bridge, but the degree of influence does not show a linear correlation with the change in radius of curvature. However, when it comes to the longitudinal displacement of the bridge, the variation in radius of curvature has a minor effect under various loading conditions.

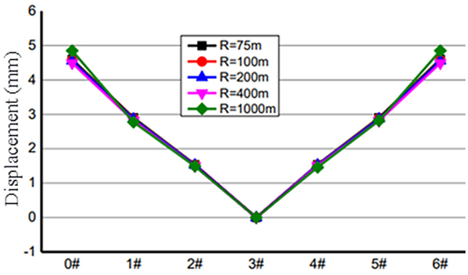

Fig. 31. Comparison of longitudinal displacement of the main beam under temperature gradient increase

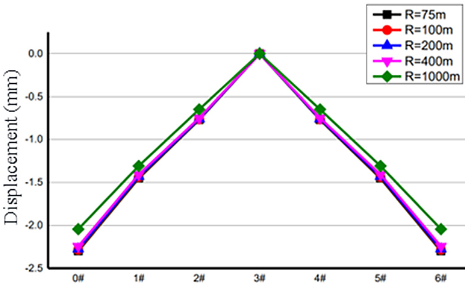

Fig. 32. Comparison of longitudinal displacement of the main beam under temperature gradient decrease

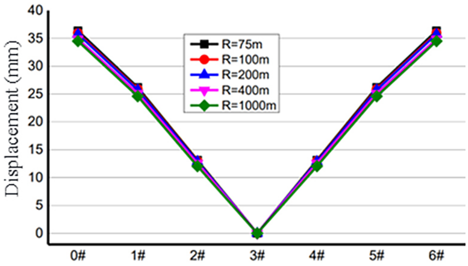

Fig. 33. Comparison of longitudinal displacement of the main beam under overall temperature increase

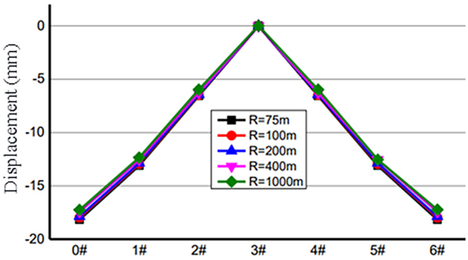

Fig. 34. Comparison of longitudinal displacement of the main beam under overall temperature decrease

5.6. The degree of influence of a stuck expansion joint on beam deflection

The steel expansion devices on the deck of the Gongbin Road overpass bridge are filled with accumulated sediment, causing the expansion joints to fail, as shown in Fig. 35. The outer side abutment back of the main bridge at Abutment 0 is locked to the top of the main beam, resulting in concrete cracking and damage, as shown in Fig. 36. This condition hinders the normal extension and deformation of the main beam.

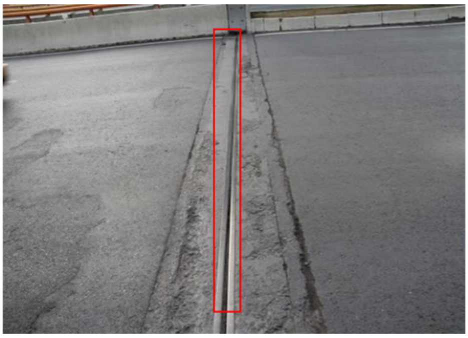

Fig. 35. D0# Expansion joint blockage

Fig. 36. D0# Abutment outer side abutment top settling and cracking

When the expansion joint fails due to blockage and becomes immobilized, it effectively imposes longitudinal constraints on the bridge. This prevents the bridge from freely expanding and contracting along the longitudinal direction. When subjected to temperature loads, the bridge cannot longitudinally expand and contract, resulting in significant horizontal thrust within the curved beam. It causes abnormal horizontal displacement and prevents the displacement from recovering when the load is removed, leading to beam deflection and posing a risk to bridge integrity. Therefore, the proper functioning of the expansion joint has a significant impact on the lateral displacement of curved beam bridges.

Based on the computational model, when the expansion joint is stuck, the variation in displacement due to the settlement of the supports is not significant. The discussion primarily focuses on the displacement changes under temperature effects and vehicle loading. The system temperature increase is considered as 20°, and the system temperature decrease is considered as 30°. The temperature gradient decrease is considered as 8.5°, and the temperature gradient increase is considered as 8.5°. The variations in gradient temperature, system temperature, and lateral displacement under intact and stuck expansion joint conditions are shown in Fig. 37 to Fig. 44.

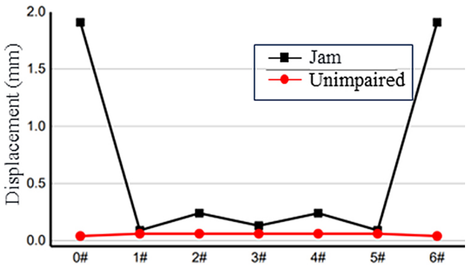

Fig. 37. Comparison of lateral displacement of the main beam under temperature gradient

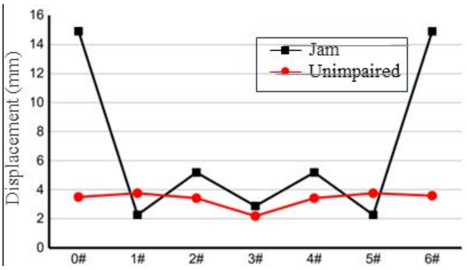

Fig. 38. Comparison of lateral displacement of the main beam under system temperature

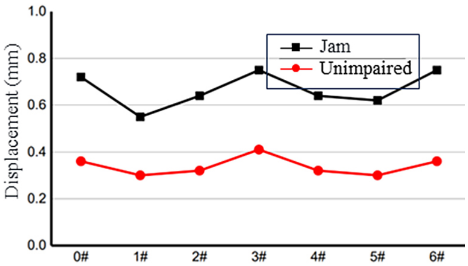

Fig. 39. Comparison of longitudinal displacement of the main beam under vehicle loading

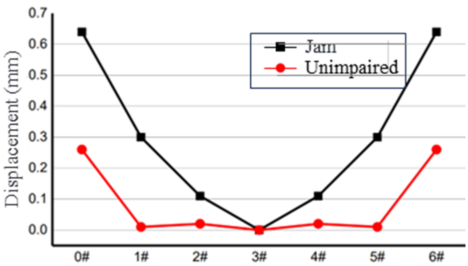

Fig. 40. Comparison of longitudinal displacement of the main beam under self-weight loading

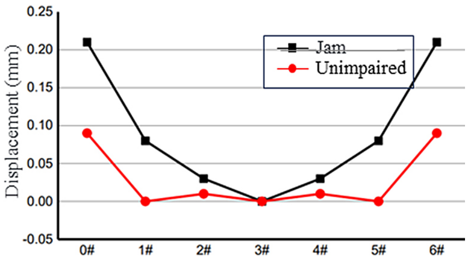

Fig. 41. Comparison of longitudinal displacement of the main beam under Phase 2 loading

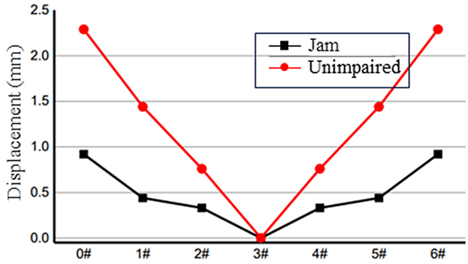

Fig. 42. Comparison of longitudinal displacement of the main beam under gradient temperature

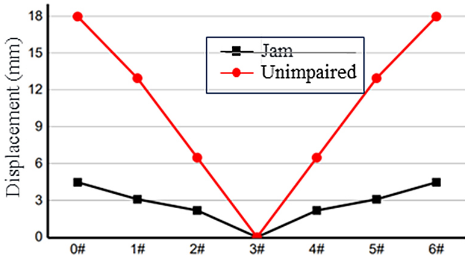

Fig. 43. Comparison of longitudinal displacement of the main beam under system temperature

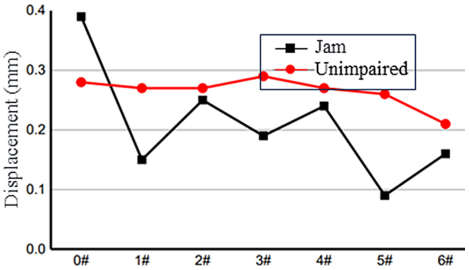

Fig. 44. Comparison of longitudinal displacement of the main beam under vehicle loading

From the above charts, it can be seen that under the condition of a stuck expansion joint, the aforementioned factors also have a certain impact on longitudinal displacement, but the magnitude of the impact is relatively smaller compared to the increase in lateral displacement. The system temperature load results in the largest reduction in longitudinal displacement, mainly due to the restriction of longitudinal displacement caused by the stuck expansion joint, which in turn increases the lateral displacement.

The stuck expansion joint has a significant impact on both the lateral and longitudinal displacements of the bridge. The effect on lateral displacement is particularly pronounced. Therefore, when a blocked expansion joint is discovered during bridge inspection, it is necessary to promptly clean it.

6. Conclusions

The study investigated the influence of various load factors on the transverse and longitudinal displacements of the D0–D6 spans of the Gongbin Road viaduct in Harbin, Heilongjiang Province, China. Furthermore, it analyzed the impact of different support forms, system temperature, stuck expansion joints, and different curvature radii on the transverse and longitudinal displacements of the curved continuous beam bridge. The study summarized the displacement patterns of the bridge under the influence of different factors.

1. Under various load conditions, temperature load (specifically system load) has a significant impact on the displacement of curved beam bridges. Its influence is greater than the combined displacement caused by self-weight, phased construction, gradient load, vehicle load, and support settlement. When the overall temperature increases by 20 degrees, the maximum lateral displacement occurs at the 0# and 6# pier abutment sections, reaching 18.0 mm, which is several times larger than the displacements caused by other loads. The system temperature load is the primary factor causing longitudinal displacement of the beam.
2. Each curved beam bridge has its own curvature radius. As the curvature radius increases, the impact on the transverse and longitudinal displacements of the curved beam bridge decreases. The relationship between the rate of increase in curvature radius and displacement is not linear. However, when the curvature radius (R) exceeds 400 m, the influence on the transverse and longitudinal displacements of the bridge can be considered negligible.

3. During operation, when the expansion joint of a curved bridge fails, the bridge is unable to freely expand and contract longitudinally. The combination of temperature load and concrete shrinkage and creep leads to abnormal displacements of the bridge. The magnitude of displacement is 2 to 3 times greater than the normal working condition of the expansion joint. Furthermore, these displacements cannot be fully restored, resulting in a deformation-related bridge disorder.

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