Scholar Publishing Group
International Journal of Big Data Intelligent Technology
https://doi.org/10.38007/IJBDIT.2024.050117
ISSN 2790-0932 Vol. 5, Issue 1: 161-171

Research on the Evaluation of Vertical Curvature Line Shape for Ballastless Track Laying on a 420m Extra-large Span Double-track Truss Strengthened PC Box Girder Cable-stayed Bridge

Jun Gao[1,2,3,4,a*], Hongxiong Lu[5], Zhongxi Guo[5], Zhiguo Liu[5], Chan Mei[5], Jian Zhang[6]

[1]*Wuhan University of Technology, Wuhan 430017, Hubei, China*

[2]*Wujiu Railway Passenger Dedicated Line Hubei Co., Ltd., Wuhan 430012, Hubei, China*

[3]*Inner Mongolia Autonomous Region Department of Transportation, Hohhot 010020, Inner Mongolia, China*

[4]*Wuhan-Guangzhou Railway Passenger Dedicated Line Co Ltd., Wuhan 430012, Hubei, China*

[5]*China Railway Eleventh Bureau Group First Engineering Co., Ltd., Xiangyang 441000, Hubei, China*

[6]*Hunan Limited Liability Company of Shanghai-Kunming Railway Passenger Dedicated Line, Changsha 410007, Hunan, P.R. China*

[a]*1003296988@qq.com*

[*]*corresponding author*

Keywords: 420m double-track steel truss; cable-stayed bridge; ballastless track; vertical curvature radius; line shape evaluation

Abstract: Laying ballastless tracks on long-span bridges has always been a technical challenge in bridge and track engineering. Tall piers and long spans a series of characteristics such as large structural weight, large deformation, and large beam end rotation angles. Under the action of train loads, temperature loads, creep, other loads, the deformation is complex, making it difficult to maintain track smoothness. With the continuous in-depth research and development of ballastless track technology on-span bridges, laying ballastless tracks on long-span bridges and achieving high-speed operation has become the main technical breakthrough. The 60m chord measurement method the evaluation method of the vertical deformation radius of the mid-span vertical curve are used to assess the smoothness of the track surface, and the applicability of layingastless tracks on a 420m double-track steel truss reinforced PC box girder cable-stayed bridge is concluded. This has important reference significance the study of related engineering problems.

1. Introduction

The construction of ballastless tracks on long-span bridges has always been a technical challenge in bridge and track engineering. Tall piers and spans have a series of characteristics such as large structural weight, large deformation, and large beam end rotation angles. Under the action of train loads, temperature loads, creep, the deformation is complex, and it is difficult to maintain track smoothness. To adapt to the large deformation characteristics of long-span bridges, most of the and under-construction bridges over 400 meters in China are equipped with ballasted tracks. For instance, the Tongling Yangtze River Road-Rway Bridge on the Hefu High-Speed Railway, the Shanghai-Nantong Yangtze River Bridge, and the Wufengshan Yangtze River in Zhenjiang all have main spans reaching the kilometer level, and all are equipped with ballasted tracks. However, the biggest drawback of ballasted tracks that their geometric shape and smoothness are difficult to maintain. After significant deformation of the long-span bridge, it is easy for the ballast to flow, leading a large amount of maintenance work. Additionally, the presence of ballasted tracks can cause speed restrictions in certain sections of the line; Furthermore, inserting a small section ballasted track in the middle of a ballastless track segment increases the variety of maintenance equipment needed, thereby raising the operational maintenance costs. Therefore, researching the of ballastless tracks under the conditions of ultra-long span bridges has significant engineering significance [1-6].

2. Project Overview

The Xi'an to Shiyan railway project is located in the southeastern part of Shaanxi Province and the northwestern part of Hube Province, and it is a project in the medium and long-term railway network plan. The route starts from Xi'an in Shaanxi Province, crosses the Qin Mountains to the southeast, passes through the cities of Shangluo and Shiyan, and connects with the already operational Wuhan to Shiyan railway, forming fast railway passenger channel from Xi'an to Wuhan. The route passes through the Wei River Basin and the Qinling Mountains, connecting the Guanzhong Plain the Jianghan Plain. It successively passes through the districts of Baqiao, Chang'an, and Lantian in Xi'an, the districts of Shzhou and Shanyang in Shangluo, and the counties of Yunxi, Yunyang, and Zhangwan in Shiyan. The new main line from'an East Station (inclusive) to Shiyan East Station (exclusive) is 255.791 km long. The Hanjiang Special Bridge is key project on the Xi'an to Shiyan railway, crossing the Hanjiang River near Youfanggou in Yunyang County, Shiyan City. The Han Special Bridge has a total length of 917.45 meters. The span arrangement is (67+70+73+42+73+70+67) meters for the main bridge and 2×32 meters for the simple-supported beams. The small mileage end of bridge connects to a tunnel, and the large mileage end connects to an embankment. The main bridge uses a main span, with the bridge deck elevation at 234 (top of the rail), and the distance from the bridge deck to the highest navigable water level of the Hanjiang River is about 6 meters.

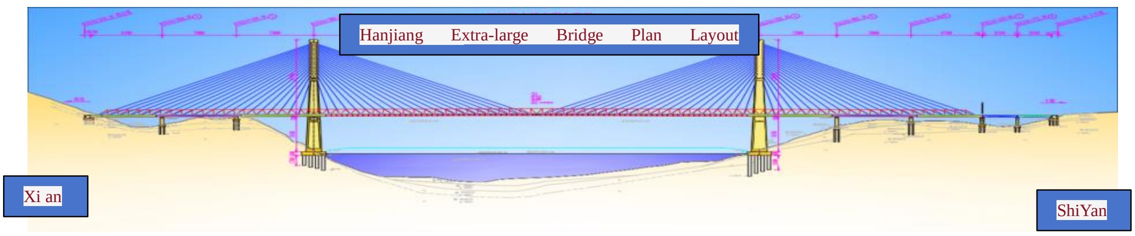

Fig 1. Layout of the Hanjiang Special Bridge

3. Challenge Analysis

3.1 Complex Vertical Deformation of Long-Span Bridges

For long-span bridges, especially flexible system bridges as cable-stayed bridges, whether laying ballastless tracks or ballasted tracks, issues such as large deflection-to-span ratio, significant mid-span vertical deformation and whether they can meet the requirements of high-speed operation at 350 km/h need to be addressed [7-10]. Compared to ballasted, ballastless tracks, once poured, cannot be adjusted, and the deformation of the bridge in both vertical and horizontal directions is directly reflected on the track surface When the main span of the bridge exceeds 300 meters, the mid-span vertical deflection under the action of temperature and train loads often exceeds 20 mm. The vertical deformation curve of long-span bridges is complex, and further analysis is needed to determine whether the smoothness and dynamic and static performance of long bridges under different loads meet the relevant requirements.

3.2 Adaptability of Track Structures to Beam End Deformations in Long-Span Bridges

Under the action train loads and temperature, long-span bridges experience large beam end deformations and complex deformation patterns [11]. Additionally, long-span bridges are equipped with expansion devices rail expansion regulators at the beam ends. The complex beam end deformations combined with the relatively weaker track equipment lead to a concentration of track defects at the beam ends long-span bridges [12-13].

4. Evaluation of the Vertical Curvature Radius Profile Based on Ballastless Track Laying

4.1 Single Load Calculation

4.1.1Selection of Single Load Values

The single-directional loads for long-span cable-stayed bridges include train axle loads, temperature loads, and shrinkage creep. these, the temperature load includes overall temperature load, as well as the heating and cooling loads of the stay cables, steel trusses, bridge panels, and bridge.

(1) Train Axle Loads The actual train axle loads are applied to the bridge structure to simulate the deformation of the bridge when the train passes. The of the train axle load is shown below:

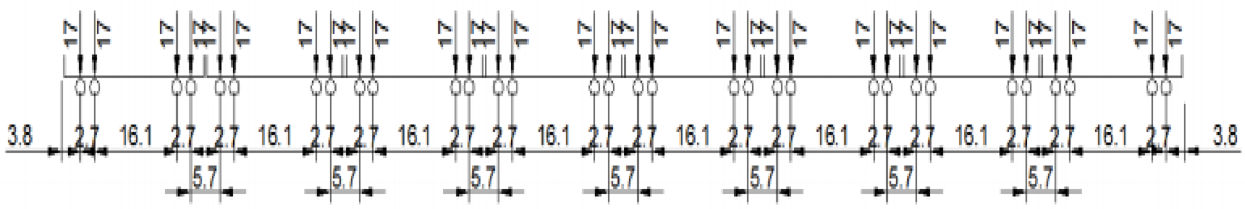

Fig. 2 Schematic diagram of train axle weight load

(2) Temperature Loads

1) Overall Temperature Increase/Decrease Based on the local climate conditions, the design closure temperature is to be 15 ℃, with the bridge system's temperature change valued at ±20 ℃ for overall temperature increase/decrease.

2) Temperature Differences temperature difference between the stay cables and concrete beams,

as well as between the stay cables and concrete bridge towers, is: 15℃ for temperature increase,10℃ for temperature decrease. The temperature difference between the steel trusses and concrete beams is: 15℃ for temperature increase, 10℃ temperature decrease. For the temperature loads on steel trusses and stay cables, starting from the working temperature of 15℃, the highest temperature after temperature increase can reach 15 20 15=50℃, and the lowest temperature after temperature decrease combination can reach 15-2010=-15℃. According to the meteorological data of Yunxi County, the extreme highest temperature is 41.8℃, and the lowest temperature is -8.6℃. Therefore, the temperature increase combination and temperature decrease combination can reflect the most unfavorable temperature conditions.

3) Temperature Gradient temperature difference between the two sides of the concrete bridge tower is ±5℃. The temperature difference along the thickness of the concrete main beam's top plate is taken to the "Design Code for Railway Bridge and Culvert Concrete Structures" (TB10092-2017) as follows: Given the latitude of the Hanjiang Special Bridge is 32.8° and the atmospheric transparency is general, a=5, T0=21. For top plate with a thickness of 40cm, considering a 6cm concrete cover thickness, the nonlinear temperature difference load on the top plate is shown in the figure.

4.1.2Load Calculation Results

The vertical deformation results of the Hanjiang Extra-large Bridge under various individual loads are shown in Table 1 below.

Table 1. Vertical Deformation Calculation Results of the Hanjiang Extra-large Bridge under Individual Loads

No.	Condition	Vertical Displacement of Bridge/mm	Distance from Midspan/m
1	ZK Load	315.6	0
2	Actual Operating Load	116.8	0
3	Overall Temperature Increase/Decrease of 20℃	9.02/8.65	±210
4	Cable Temperature Increase/Decrease Steeluss Temperature	77.3/65.7	0
5	Increase/Decrease Bridge	3/2	0
6	Deck Temperature Increase/Decrease	2.27/0.9	0
7	Bridge Tower Single Side Temperature Increase/Decrease	2.93	0

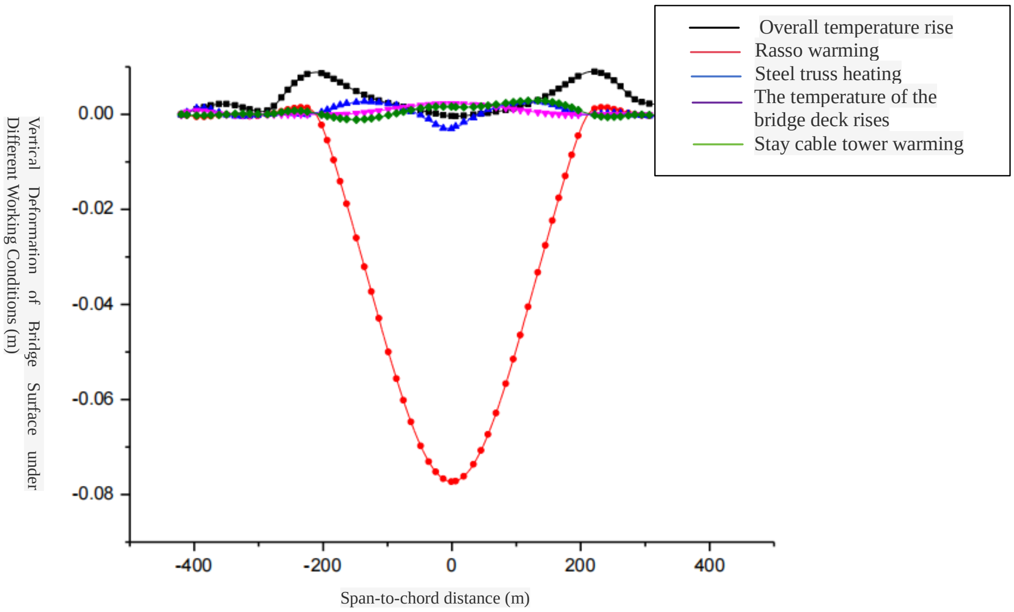

Fig.3 Bridge deformation data under the action of static temperature rise conditions of the Hanjiang Special Bridge

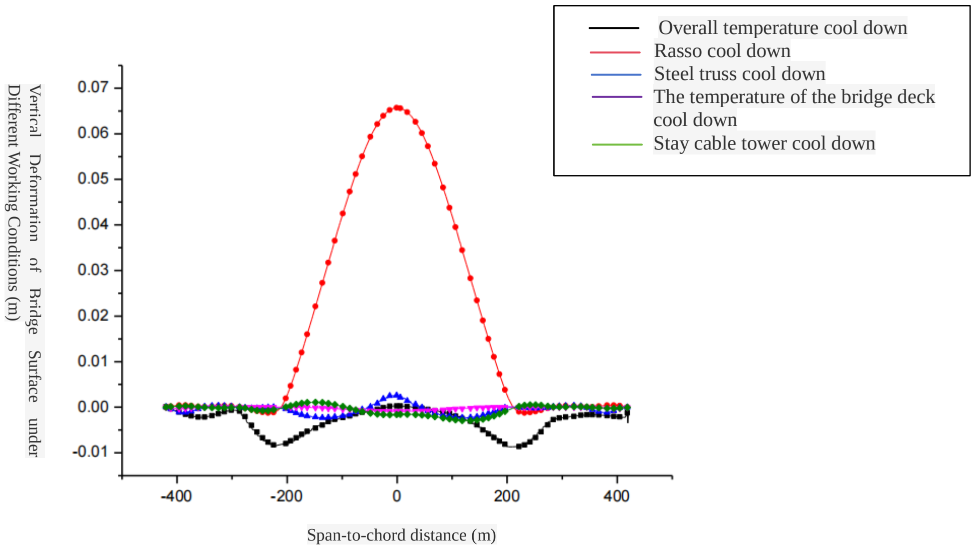

Fig.4 Bridge deformation data under static cooling conditions of the Hanjiang Special Bridge

4.1.3Conclusions

When the entire bridge is subjected to temperature rise and fall, the deformation of the bridge shows symmetry, similar deformation amplitudes during both heating and cooling.

The deformation of the bridge surface under the temperature rise and fall conditions of the stay cables is significant.

4.2Evaluation of 60m Chord Measurement Calculation Results

Heating and Cooling Conditions The 60m measurement values under heating and cooling conditions were calculated, and the results are shown in Table-2.

Table 2. Filtered calculation results of the 60m measurement method for heating and cooling conditions of the Hanjiang Special Bridge

Working Condition	Calculation Results of 60m Chord Method (mm)	Maximum Chord Irregularity and Midspan Distance (m)
Heating combination	3.16	-213
Heating combination	2.85	-283

The maximum filtered value of the 60m chord measurement method for the deformation of the Hanjiang Special Bridge under temperature load is 3.16mm.

Three-year Creep The maximum filtered value of the 60m chord measurement method under creep action is 227mm (located at the midspan). Three-year Creep Temperature Increase/Decrease Combination The 60m chord measurement method, as main standard for static acceptance of large-span bridge construction points at present, does not consider the effect of vehicle live load, and since shrinkage creep has the characteristics short-term occurrence and long-term slow change, only the deformation under temperature action is considered in the static acceptance process. Therefore, when simulating the 60 chord measurement method, only the temperature load is considered. The maximum filtered value of the 60m chord measurement method for the deformation of the Hanjiang Special under temperature load is 3.16mm, which meets the static acceptance standard [14-16]. According to the analysis of domestic railway data the maximum value of the 60m chord height irregularity after fine adjustment of the ballastless track is less than 1mm. Considering the complexity the actual site conditions and the difficulty of fine adjustment work for large-span bridges, a certain amount of redundancy is considered. The maximum value of the 60 long chord height irregularity after fine adjustment of the ballastless track is temporarily set at 2mm. Combined with the temperature load, the maximum value of 60m chord measurement for the Hanjiang Special Bridge is 5.16mm, which meets the control standard of 7mm.

Table 3. Calculation Results of the 60m Hanjiang Special Bridge after Temperature Cycling and Creep Chord Method Filtering

Working Condition	Calculation Results of 60m Chord Method (mm)	Maximum Chord Irregularity and Midspan Distance (m)
Heating combination+Creep	4.73	-214
Heating combination+Creep	3.51	-283

4.3 Evaluation Method for Midspan Vertical Curve Radius and Bridge Deck Vertical Line Curvature Radius Considering the complexity of bridge deformation caused by dynamic train

This report simulates the train entering the bridge on a double track, starting from the left pier position, with each 1/8 step load increment, the train head reaches the right pier position. The train live load loading position is shown in the following fig.5:

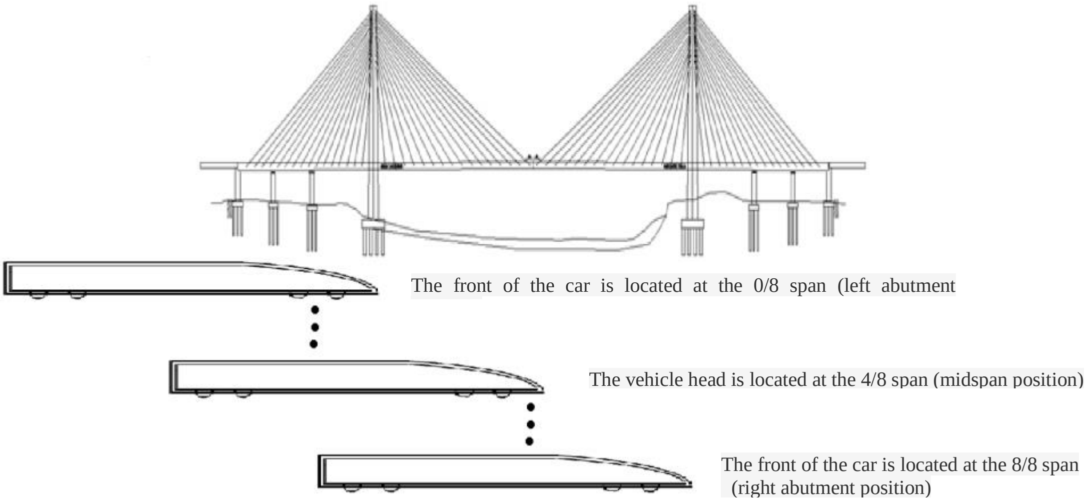

Fig.5 Schematic diagram of train live load gradually loading from the left side entering the bridge

4.3.1. Calculation Results

The vertical deformation curve of the girder during the gradual ascent of the vehicle onto the Hanjiang Special Bridge was and analyzed. The results of the vertical deformation and curvature radius of the girder under different working conditions are summarized and compared in Figures6,7,8,9 and10 8[17-19].

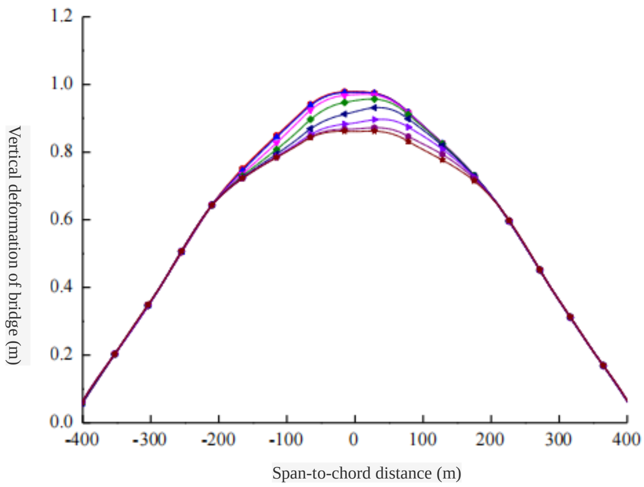

Fig.6: Bridge temperature rise, vehicle load from the left pier into the bridge gradually loading the beam surface deformation curve

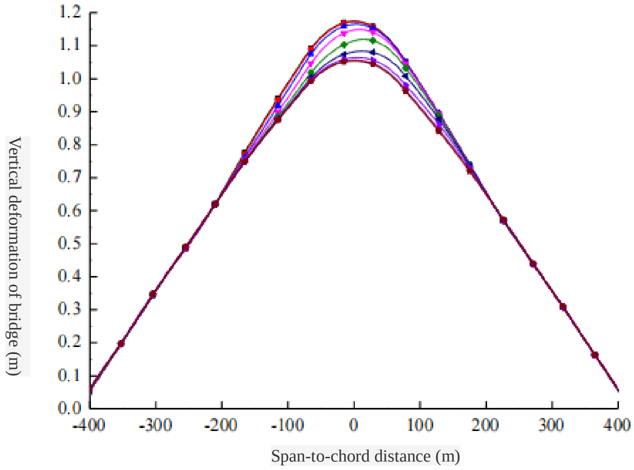

Fig.7: Bridge deck deformation curve under vehicle loading from the left pier during cooling

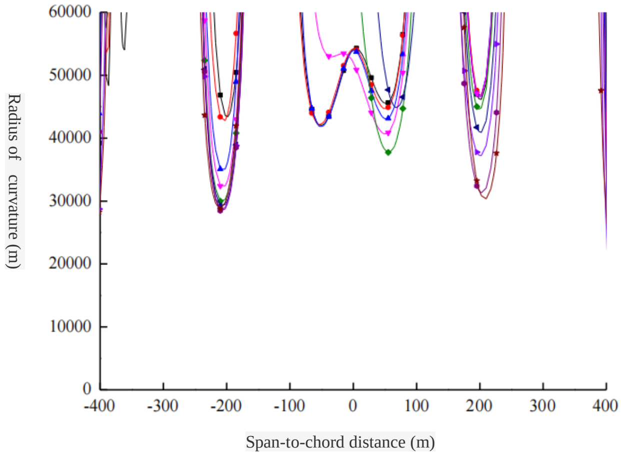

Fig. 8 The vehicle load enters the bridge from the left pier and gradually loads the curvature radius of the girder when the bridge is heated

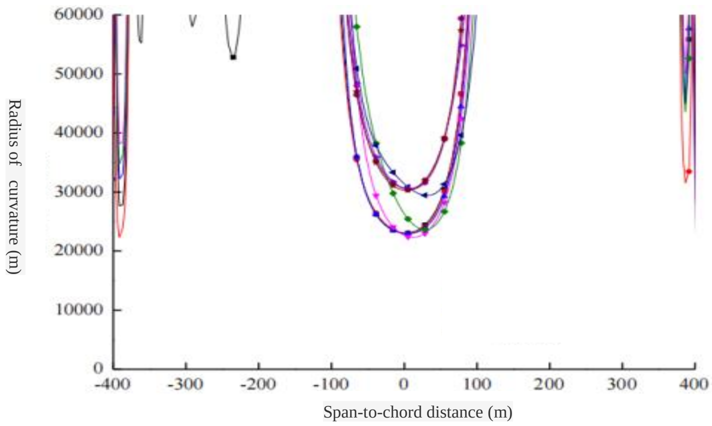

Fig.9 The curvature radius of the bridge deck gradually increases as the vehicle load moves from the left pier onto the bridge during cooling

During the gradual loading of the vehicle body, the curvature radius of the deformation curve within the vehicle body range was extracted, and the minimum values and corresponding evaluation were calculated as shown in Table-4

Table 4 Summary Table of Calculation Results for the Curvature Radius Method of the Hanjiang Special Bridge under Various Conditions

Working condition	Minimum curvature radius calculation results	Whether it meets the smoothness requirements
1	30175	Meet the smoothness standards
2	30659	
3	30289	
4	30332	
5	36355	
6	40587	
7	44710	
8	57382	
9	63650	
10	67901	
11	70610	
12	68942	
13	66071	
14	78406	
15	80000	
16	80000	
17	80000	
18	80000	

4.3.2 The analysis conclusions are as follows

(1) After simplification, the deformation range of the main span of thejiang Extra-large Bridge has three vertical curves. Due to the large span, the straight line between the vertical curves is long, resulting in a large calculated curvature radius(2) In the temperature rise condition, as the vehicle gradually enters the bridge from the left, the minimum curvature radius within the vehicle range is Condition 1the entire bridge is loaded with train load, the minimum curvature radius within the vehicle range is 30175m), which meets the curvature radius control. (3) In the temperature drop condition, there is only one vertical curve in the track surface line. As the vehicle gradually enters the bridge from the left the minimum curvature radius within the vehicle range is Condition 13 (the vehicle head is at 4/8 span, the minimum curvature radius within the vehicle is 66071m), which meets the curvature radius control standard. (4) Under the temperature drop condition, the bridge deformation is upward, basically cancels out the downward deformation caused by the vehicle load. At this time, the deformation is small, and the curvature radius is close to the design vertical.

5 Conclusions and Recommendations

5.1Conclusions

For the issues of excessive beam surface linearity standards and-wave measurement standards, extensive research has been conducted domestically. Methods such as the 60m chord measurement method and the mid-span vertical deformation vertical curve radius evaluation are generally used to assess the vertical linearity smoothness of the track surface.

The maximum 60m chord measurement value for the Hanjiang Bridge under temperature load is 3.16mm, meeting the static standard requirements. Considering the track irregularity with a 60m chord measurement value 2mm, the maximum 60m chord measurement value is 5.16mm, which meets the static acceptance standard requirements.

The load (temperature shrinkage creep double-track train operation load), the minimum vertical curve radius of the Hanjiang Special Bridge is 76,56m, meeting the control requirement of 49,000m for the mid-span deformation radius.

The calculation results of the track surface linearity curvature radius evaluation method show that the minimum curvature radius of the Hanjiang Special Bridge is 30,175m, meeting the research limit of the curvature radius. The various indicators of the Hanjiang Special Bridge provide favorable conditions for the laying of ballastless tracks.

The analysis results the 60m chord measurement method, the mid-span vertical deformation vertical curve radius evaluation method, and the track surface vertical linearity curvature radius evaluation method all the conditions for laying ballastless tracks on a 420m double-track steel truss reinforced PC box girder cable-stayed bridge.

5.2 Recommendations

Establish a bridge and track health monitoring system, reasonably set up CPII and CPIII measurement points, and provide technical support for further improving the accuracy ofastless track laying.

References

[1] Chen S, Tang S, Zhang G, et al. Long-term performance test concrete cable-stayed bridges[J]. China Journal of Highway and Transport, 2011, 24(4): 39-49.

[2] Bentaleb F, Amara I. Modeling of Cutting Forces and Roughness by the Response Surface Method (RSM)[M]. Berlin: Springer Publishing, 2015.

[3] Zhang Y, Meng S. Long-term deformation prediction of large-span continuous rigid frame bridges based on response surface[J]. China Civil Engineering Journal, 2011, 44(8): 102-106.

[4] Ma K Xiang T, Zhao R, et al. Stochastic analysis of long-term deformation of high-speed railway reinforced concrete arch bridges[J]. China Civil Engineering Journal,2012, 45(11): 141-146.

[5] Wu Y. Study on long-term deformation stress stochastic analysis of high-speed railway large-span continuous rigid frame bridges[D]. Chengdu: Southwest Jiaotong University, 2014.

[6] Wang M. Stochastic analysis of long-term deformation of large-span prestressed concrete continuous rigid frame bridges[D]. Chengdu: Southwest Jiaotong University 2014.

[7] Xin J, Zhou J, Yang Y, et al. Application of response surface method in long-term deformation prediction of main of large-span rail cable-stayed bridges[J]. Journal of Jiangsu University (Natural Science Edition), 2016, 37(3):367-372.

[8] Jeffcoat M. The effect of experimental design parameters on the determination of sample size[J]. Journal of Periodal Research, 2010, 27(4): 320-322.
[9] Ye C, He S Hou Y. Design of simple axial tensile testing instrument and experimental study of reasonable sample size[J]. Railway Standard Design, 2016, 609): 9-15.
[10] Liu J, Wang H, Zhang Z, et al. Study on response surface model and optimization algorithm damage identification of cable-stayed bridges[J]. Railway Engineering, 2016, 56(10): 1-5.
[11] Li X, Zhou J, Yang J, et al. Analysis of static live load pre-camber setting for large-span rail cable-stayed bridges based on characteristics[J]. Science and Technology Engineering, 2016, 16(6): 222-227.
[12] J, Wang D. Sensitivity analysis of static parameters of large-span cable-stayed bridges based on response surface method[J]. Highway and Transport Science and Technology,2015, 32(8): 100-106.
[13] Wang D, Tang H. Static system of cable-stayed bridges based on response surface method[J]. Journal of Transportation Science and Engineering, 2014, 30(2): 4-39.
[14] Guan H, Shangguan X. Stochastic analysis of construction errors in concrete cable-stayed bridges[J China Journal of Highway and Transport, 2013, 33(1): 159-163.
[15] Yu, Wu Y, Su X. Study on shape optimization prediction of large-span concrete cable-stayed bridges[J]. Journal of Railway Science and Engineering, 208, 15(1): 133-140.
[16] Yu S, Zhou L, Ou J. Finite element correction of ultra-large span suspension bridges based on radial basis function response surface method[J]. Journal of Railway Science and Engineering, 2014, 1(1): 1-9
[17] Xie M, Bu Y, Zhang K, et al. Sensitivity analysis of geometric control parameters of-large span hybrid beam cable-stayed bridges[J]. Journal of Chang'an University (Natural Science Edition), 2014, 34(3):66-73.
[18] Wang Shengwu, Xiang Chunfu, Li Tengteng, et al. Parametric sensitivity analysis of an single-tower cable-stayed bridge[J]. Highway Engineering, 2015, 40(1):137-14.
[19] Liang Zongbao. Research on Bridge Structural Safety Evaluation Based on Monitoring Information Statistical Analysis [D]. Chqing: Chongqing University, 2006.