Study on Mechanical Properties of Simply Supported Girder Bridge after Jointless

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Abstract. The jointless bridges includes integral bridges, semi-integral bridges and extended deck bridges. The integral bridges adopts an integral abutment, and its main girder, abutment and pile under abutment are fixed together to bear the force together. The expansion joint and expansion device are cancelled, and the integrity, durability and driving comfort of the bridge are improved. In this paper, a simply supported girder bridge in Fujian Province of China is taken as the research background, and it is transformed into an integral bridge. Midas/Civil software is used to establish the finite element models of the original bridge and the integral bridge, and the mechanical properties of the main girder and the pile under the combined action of dead load and overall temperature rise of 25 °C are analyzed. The results show that due to the consolidation of the main girder and abutment of the integral bridge, the internal force at the girder end under the combined action of temperature and dead load is greater than that of the simply supported beam bridge. The pile deformation of the integral bridge is significant under the combination of temperature and dead load. With the increase of the height-to-thickness ratio of the abutment of integral bridge, the bending moment at the girder end and the mid-span are increasing. Different abutment height-to-thickness ratio has little influence on the horizontal displacement of the girder end of integral bridge. With the increase of height-to-thickness ratio of the abutment of integral bridge, the deformation of pile decreases. The flexible abutment with large height-to-thickness ratio can improve the mechanical properties of pile and achieve the purpose of protecting the pile.

Keywords. Jointless Bridges; Finite Element; Longitudinal Mechanical Properties; Abutment Height-to-Thickness Ratio

1. Introduction

Because the expansion joints, expansion devices and bearing of integral bridges are cancelled, the integrity and durability of the structure are significantly improved, and the service life of the structure is increased [1-2]. It is currently one of the most studied jointless bridges in the world [3-4]. Compared with the bridge with expansion joint, the integral bridge is greatly affected by temperature. The reciprocating deformation caused by thermal expansion and cold contraction of main girder is mainly borne by pile, which leads to significant pile-soil interaction [5-8].

According to the survey in 2004 in the United States, due to the damage of the bridge deck, the cases of transforming the bridge deck with expansion joints to those without expansion joints are increasing day by day [9]. For simply supported girder bridges, jointless technology can be used to transform them into jointless bridges [6]. Among them, the integral bridge has the best integrity and durability, and is the preferred bridge type in jointless transformation [10-11]. In the application of jointless technology in China, the bridge with expansion joints is more transformed into an extended deck bridges [12].

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Based on a simply supported girder bridge in Fujian Province of China, the finite element models of two bridge types are established to study its mechanical properties, and the influence of different height-to-thickness ratio of the abutment on the mechanical properties of the integral bridge is analyzed.

2. Transformation of simply supported girder bridge into integral bridge

Taking a simply supported girder bridge in Fujian Province of China as the background, the bridge has a total length of 52.8 m and a span of 3×16 m, as shown in Figure 1. The superstructure is a 3-hole reinforced concrete hollow slab girder with a span of 16 m, and the main girder is made of C50 concrete. The substructure adopts reinforced concrete double column piers to connect the cast-in-place pile foundation, and the abutment adopts an embedded abutment, and the concrete strength grade is C50.

![Figure 1. Overall layout of original bridge (Unit: mm)](image)

In this paper, the original bridge is transformed into an integral bridge, and the approach slab is set behind the abutment to play a transitional role with the road behind the abutment and transfer part of the horizontal deformation of the main girder. The overall layout of the transformed integral bridge is shown in Figure 2.

![Figure 2. Overall layout of integral bridge (Unit: mm)](image)

3. Establishment of finite element model

Midas/Civil is used to establish 3D finite element models of the original bridge and the transformed integral bridge, as shown in Figure 3. The main girder is modeled by the grillage method. The main girder is connected laterally by a virtual girder, and the rotation constraint of the transverse girder ends of the girder is released to simulate the transverse hinged connection of the main girder. The original bridge model has 1434 nodes and 2803 elements, and the integral bridge has 1558 nodes and 3127 elements. Rubber bearing is set on the top of pier of the two types of bridges, elastic connection is used in the model to simulate. The piers, abutments and piles are all rigidly connected. Among them, the main girder and abutment of the integral bridge adopt rigid connection. In addition, the bottom of the pile adopts fixed connection simulation. The pile-soil interaction of the two types of bridges is simulated by soil springs, and the static earth pressure behind the abutment was considered respectively. Among them, the integral bridge abutment takes into account the influence of the active and passive earth pressure behind the abutment, and nonlinear soil springs were set behind the abutment for simulation. The stiffness of the pile-soil spring is calculated using the "m" method in the "Specifications for Design of Foundation of Highway Bridges and Culverts" (JTG 3363-2019) [13].
4. Analysis of mechanical properties of simply supported girder bridge after jointless

4.1. Mechanical properties analysis of main girder

The integral bridge is the most sensitive to the influence of temperature. Therefore, the influence of the combination of dead load and temperature change on the mechanical properties of the integral bridge is considered in the study, and it is compared with the simply supported girder bridge. Considering that the influence of temperature rise and fall on the structural force is similar and the value is opposite, only the influence of the overall temperature rise is considered in the study. The load condition is the combined action of overall temperature rise of 25 °C and dead load.

Table 1 shows the internal force and deformation of the original bridge and the integral bridge after the transformation. It can be seen that the bending moment at the girder end of the integral bridge is relatively large, which is mainly due to the consolidation of the girder end and abutment of the integral bridge, which results in a larger internal force under the combined action of temperature and dead load. The mid-span bending moment of the simply supported girder bridge is larger than that of the integral bridge, and the error between the two is 53.5%. The shear forces at the girder ends of the simply supported girder bridge and the integral bridge are basically the same, which indicates that the shear deformation of the girder end
of the two bridges is basically the same. The mid-span bending moment of simply supported girder bridge is larger than that of the integral bridge, and the error between the two is 13.2%. At the same time, it can be seen that the horizontal displacement of the end of the main girder of the simply supported girder bridge and the integral bridge are basically equal. In summary, the integral bridge after the transformation improves the mid-span mechanical properties of the main girder, and its mid-span internal force is smaller than that of the simply supported girder bridge.

| Table 1. Internal force and deformation of simply supported girder bridge and integral bridge |
|---------------------------------|------------------|------------------|
| Bridge type                     | Simply supported girder bridge | Integral bridge |
| Girder end bending moment       | 0                 | -783.7           |
| (kN·m)                          |                   |                  |
| Mid-span bending moment         | 557.2             | 259.3            |
| (kN·m)                          |                   |                  |
| Girder end shear force          | -155.1            | -152.5           |
| (kN)                            |                   |                  |
| Mid-span shear force            | 145.7             | 126.4            |
| (kN)                            |                   |                  |
| Horizontal displacement of girder end | 2.384         | 2.347            |
| (mm)                            |                   |                  |

4.2. Mechanical properties analysis of pile under the abutment

Under the action of temperature load, the pile of the integral bridge will produce large horizontal reciprocating deformation, which is one of the weakest parts of the integral bridge. Therefore, this section considers the combined action of the dead load and the overall temperature rise of 25℃ to analyze the mechanical properties of the piles under the abutment of the integral bridge and compare it with the simply supported girder bridge.

Figure 4 shows the pile deformation of integral bridge and simply supported girder bridge under the combined action of dead load and overall temperature rise of 25 ℃. It can be seen that the deformation of pile in simply supported girder bridge is very small. The pile deformation of the integral bridge is significant, and the maximum deformation value is 6.4mm, mainly because the abutment of the integral bridge is consolidated with the main girder, under the combined action of temperature and dead load, the deformation of the superstructure will cause the together deformation with the substructure.

Figures 5 and 6 show the bending moment and shear force of the piles under the combined action of the dead load and the overall temperature rise of 25℃ for the integral bridge and the simply supported girder bridge. It can be seen that both bending moment and shear force of integral bridge are larger than that of simply supported girder bridge. This is mainly due to the consolidation of the main girder, abutment and piles of the integral bridge, the deformation of the superstructure will cause greater deformation of the pile, leading to greater internal force of the pile. The maximum bending moment of the integral bridge increased by 57.1% compared with that of the simply supported girder bridge. The maximum shear force increases by 63.3% compared with that of the simply supported girder bridge.
Figure 4. Deformation of the pile

Figure 5. Bending moment of the pile

Figure 6. Shear force of the pile
5. Parameter analysis

The abutment height-to-thickness ratios of the integral bridge were selected as 0.92, 1.11, 1.29, 1.48, 1.66 and 1.85 respectively as parameters to analyze the influence of different abutment height-to-thickness ratios on the mechanical properties of the integral bridge main girder and pile under the abutment.

5.1. Analysis of the mechanical properties of the main girder of the integral bridge

Table 2 shows the internal force and deformation of the main girder corresponding to the different height-to-thickness ratios of the abutment of the integral bridge. It can be seen that as the height-to-thickness ratio of the abutment increases, the bending moments at the end of the girder and the mid-span are increasing, and the maximum and minimum errors of the bending moment at the girder end and mid-span corresponding to different height-to-thickness ratio of abutment are respectively 13.0% and 7.5%. The girder end shear force increases with the increase of the abutment height-to-thickness ratio, but the mid-span shear force decreases with the increase of the height-to-thickness ratio. The maximum and minimum errors of the girder end and mid-span shear force corresponding to different height-to-thickness ratios of the abutment are 4.8% and 5.6%, respectively. It can also be seen that the different height-to-thickness ratios of the abutment have little influence on the horizontal displacement of the girder end.

| Height thickness ratio | 0.92 | 1.11 | 1.29 | 1.48 | 1.66 | 1.85 |
|------------------------|------|------|------|------|------|------|
| Girder end bending moment (kN·m) | -721.1 | -749.7 | -774.5 | -795.8 | -813.9 | -829.2 |
| Mid-span bending moment (kN·m) | 259.3 | 264.5 | 269 | 273.1 | 276.6 | 279.8 |
| Girder end shear force (kN) | -177.4 | -179.7 | -181.6 | -183.3 | -184.7 | -185.6 |
| Mid-span shear force (kN) | 126.4 | 124.4 | 122.6 | 121.1 | 119.8 | 118.6 |
| Horizontal displacement of girder end (mm) | -2.421 | -2.316 | -2.324 | -2.33 | -2.311 | -2.314 |

5.2. Analysis of the mechanical properties of the pile of the integral bridge

Figure 7 shows the pile deformation corresponding to the different height-to-thickness ratios of the abutment of the integral bridge. It can be seen that as the height-to-thickness ratio of the abutment increases, the pile deformation decreases, mainly because the greater the height-to-thickness ratio, the greater the flexibility of abutment, and the deformation is mainly absorbed by abutment while the pile deformation is very small. Therefore, it is suggested to adopt the flexible abutment with large height-to-thickness ratio in actual engineering to reduce the deformation of the pile and protect the pile.
Figure 8 shows the pile bending moments corresponding to different height-to-thickness ratios of the abutments of the integral bridge. It can be seen that both positive and negative bending moments of piles decrease with the increase of abutment height-to-thickness ratios, and the maximum error of bending moment corresponding to different height-to-thickness ratios ratio is 12.7%. This shows that the use of flexible abutment with relatively large height-to-thickness ratios can improve the mechanical properties of pile.

Figure 9 shows the pile shear force corresponding to different height-to-thickness ratios of the abutment of the integral bridge. It can be seen that both the positive shear force and the negative shear force of the pile decrease with the increase of the height-to-thickness ratio of the abutment, and the maximum error of shear force corresponding to different height-to-thickness ratio of abutment is 77.9%. It is shown again that the flexible abutment with large height-to-thickness ratio can improve the mechanical properties of piles.
6. Conclusions

This paper takes a simply supported girder bridge in Fujian, China as the research background, transforms it into an integral bridge, and analyzes the mechanical properties of the two bridge types under the combined action of dead load and overall temperature rise of 25 °C. The main research results are as follows:

1. Due to the consolidation of the main girder and abutment of the integral bridge, the internal force at the girder end under the combined action of temperature and dead load is greater than that of the simply supported girder bridge.

2. Under the combined action of temperature and dead load, the pile deformation of the integral bridge is significant, mainly because the main girder of the integral bridge is consolidated with the abutment, and the deformation of the superstructure will cause greater deformation of the substructure.

3. As the height-to-thickness ratio of the abutment increases, the bending moments of integral bridge at the end of the girder and the mid-span are increasing. The shear force at the girder end increases with the increase of the abutment height-to-thickness ratio, but the mid-span shear force decreases with the increase of the height-to-thickness ratio. Different height-to-thickness ratios of abutments have little influence on the horizontal displacement of the girder end of the integral bridge.

4. As the abutment height-to-thickness ratio of the integral bridge increases, the pile deformation decreases. mainly because the greater the height-to-thickness ratio, the greater the flexibility of the abutment, the deformation is mainly absorbed by the abutment and the pile deformation is very small.

5. The adoption of flexible abutments with relatively large height-to-thickness ratio in the integral bridge can improve the mechanical properties of the pile and achieve the purpose of protecting the pile. Therefore, it is suggested to adopt the flexible abutment with large height-to-thickness ratio to reduce the deformation of pile.

7. References

[1] BRISEGHELLA B, XUE JQ and LAN C 2014. Maximum Length of Integral Abutment Bridges Journal of Architecture and Civil Engineering 31(1) pp 104-110
[2] XUE JQ, CHEN BC and LIN JH 2018 Study of Temperature Expansion and Contraction Deformation of Bridges with Their Deck Slabs Extended by Hollow Slabs Bridge Construction 48(2) pp 37-42
[3] BRISEGHELLA B and ZORDAN T 2015 An innovative steel-concrete joint for integral abutment bridges Journal of Traffic and Transportation Engineering(English Edition) 2(4) pp 209-222
[4] CHENG L, BRISEGHELLA B and FENU L 2017 The optimal shapes of piles in integral abutment bridges Journal of Traffic and Transportation Engineering(English Edition) 4(6) pp 576-593
[5] WASSERMAN EP and WALKER JH 1996 Integral Abutments for Steel Bridges Highway Structures Design and Book 11(8) 1247-1256
[6] CHEN BC, ZHUANG YZ, HUANG FY and BRISCEGHella B 2019 Jointless Bridge (2nd Edition) Beijing China Communications Press 39 pp 342-356
[7] ERHAN S and DICLELL M 2014 Effect of Dynamic Soil–Bridge Interaction Modeling Assumptions on the Calculated Seismic Response of Integral Bridges Soil Dynamics and Earthquake Engineering 9 pp 42-55
[8] XU Z, LUO XY, CHEN BC and HUANG FY 2019 Mechanical Performance of Multi-Span Semi-Rigid Integral Bridge under Uniform Temperature Journal of Fuzhou University (Natural Science Edition) 47(5) pp 669-674
[9] Maruri R and Petro S 2005 Integral Abutments and Jointless Bridges (IAJB), 2004 Survey Summary IAJB 2005 March Baltimore Maryland 23 pp 12-29
[10] KOZAK DL, LAFAVE JM and FAHNESTOCK LA 2018 Seismic modeling of integral abutment bridges in Illinois Engineering Structures 165 pp 170-183
[11] ZORDAN T and BRISCEGHella B 2011 Analytical formulation for limit length of integral abutment bridges Structural Engineering International 21(3) pp 304-310
[12] Dong JC, XU Z and BRISCEGHella B 2015 Design and construction of jointless transformation of a multi-span simply supported hollow slab girder bridge Journal of China & Foreign Highway 35(04) pp 170-174
[13] JTG 3363 2019 Specifications for Design of Foundation of Highway Bridges and Culverts 31 pp 521-536