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Study on the Influence of Foundation Form on the Temperature Effect of Rigid-Continuous Combined Girder Bridges

Xiaoxiong Liu, Hanbing Hu

School of civil engineer, Central South University of Forestry and Technology, Changsha 410004, China

Abstract

Rigid-continuous girder bridges are widely used because of the advantages of both continuous girder bridges and continuous rigid girder bridges, and the temperature effect is an important influence factor for the occurrence of diseases of rigid-continuous girder bridges. In this paper, a rigid-continuous girder bridge under construction in Hunan Province is taken as an example, and two foundation forms are designed: Form 1 adopts the existing actual design form, i.e. bearing platform + group pile structure; Form 2 is tie girder + large diameter pile foundation structure. Midas Civil was used to establish the calculation model of the bridge with two foundation forms and analyze the temperature effect, and the stress and displacement curves of the bridge with two foundation forms under the action of temperature were obtained, and the comparison results showed that the use of foundation form 2 could reduce the temperature stress of the main girder under the action of the annual temperature difference, and the results provided theoretical basis for the selection of the structural design scheme of this kind of bridges.

Keywords

Basic Form; Rigid-Continuous Girder Bridge; Temperature Effect; Finite Element Analysis.

1. Introduction

Since the 1950s, some scholars have realised the importance of the influence of temperature difference stress on concrete bridge structures from the field investigation and analysis of cracks in concrete piers and concrete girders. With the rapid development of high pier and large span prestressed concrete box bridges, the effects and hazards of temperature differential stresses on bridge structures have gradually attracted the attention and research of the engineering community.Zhu et al[1] achieved quantification of the effects of thermal stresses on the foundation system by instrumenting and datamining a multi-span monolithic bridge abutment with remote monitoring equipment for temperature and bridge response. The foundation stresses associated with temperature changes in the superstructure were quantified by combining in-service field measurements with finite element analyses of temperature loads on selected bridges.Choi[2][3] investigated the influence of ambient temperature on bridge structures during the initial phase, and found that early changes in temperature and humidity had a more pronounced effect on the strains and stresses in the bridge structure, and evaluated this influence based on a theoretical model. Luo[4] investigated the influence of annual and local temperature effects on the Jinghe Bridge in the context of the bridge. The results showed that the abutments produced large displacements in the transverse direction of the bridge under the two-way temperature gradient loads. Tang Yao[5] and Tang Feng[6] recognised that solar radiation may have a greater impact on flexible high piers and combined this with theory to ensure that the verticality of the bridge pier abutments could meet the requirements during construction.

However, there are fewer analyses on the internal force and displacement of rigid-continuous composite girder bridges under the action of temperature. In order to study the influence of the foundation form on the temperature effect of rigid-continuous composite girder bridges, this paper takes a certain under-construction rigid-continuous composite girder bridge in Hunan as an example to design two foundation forms, and derives the theoretical data through the comparative analysis of the temperature effect of bridges with two foundation forms to provide a theoretical basis for the structural design of such bridges. This paper provides theoretical basis for the structural design of such bridges by comparing and analysing the temperature effect of the two foundation forms.

2. Object of Study and Finite Element Modelling

2.1 General Arrangement of Bridges

An under-construction rigid-continuous combined girder bridge is located in Heshan District and Ziyang District of Yiyang City. The total length (64+102+196+102+64)m, transverse using split design, single width 16.75m, the main girder using C60 concrete, box girder root girder height of 13m, spanning the middle girder height of 4.4m, the main pier for the double limb thin-walled piers, using C50 concrete. The foundation of the main pier adopts the whole circular bearing platform, with a diameter of 31.2m and a thickness of 6m, and 37 piles with a diameter of 1.8m are set up under the single bearing platform, with a pile length of 60m; the bearing platform and the tie beams are made of C30 concrete, and the pile foundation is made of C25 concrete. The overall arrangement is shown in Fig 1.

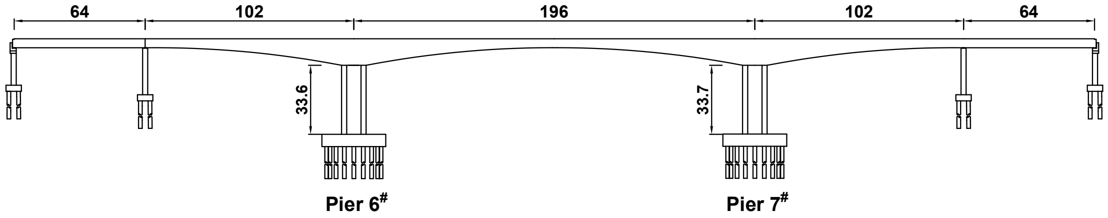
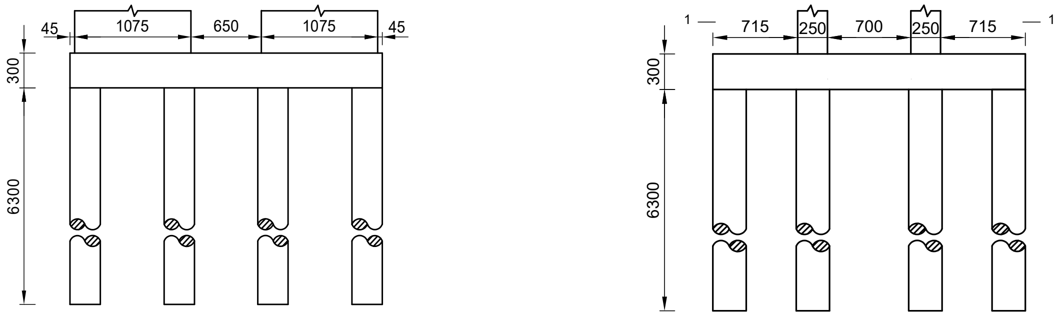


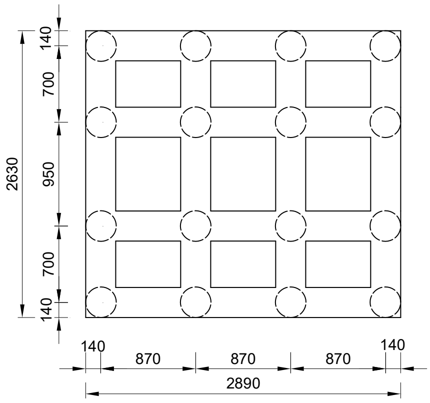
Fig. 1 Layout of the main bridge

2.2 Bollard + Large Diameter Pile Foundation Structure Design

The size of pile foundation refers to the design of similar bridges, in order to ensure the requirement of bearing capacity, the total cross-sectional area of control piles is basically equal to that of form one, and 16 piles of Φ2.8m are used. The pile distance is 8.7m in transverse direction, 7m in longitudinal direction and 9.5m in inner direction. pile length is 63m, and the elevation of pier bottom is the same as that of Form I. The top of the pier is 2.8m wide x 3m high. The top of the pier is set with 2.8m wide×3m high tie beams, and the overall plan size is 26.3m longitudinally×28.9m transversely.The structure of the foundation form II is shown in Fig.2.



(a) Bridge transverse (b) Bridge longitudinal

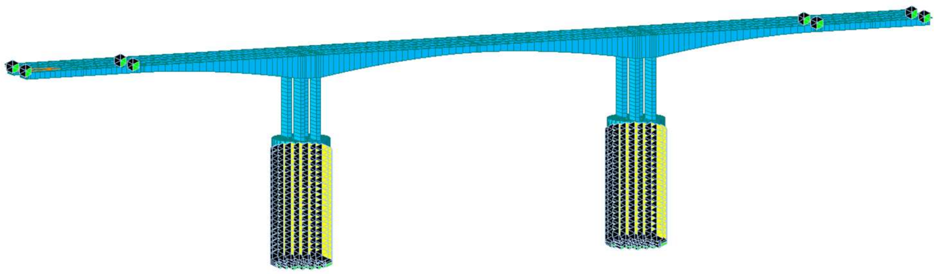


(c) Foundation layout plan 1-1

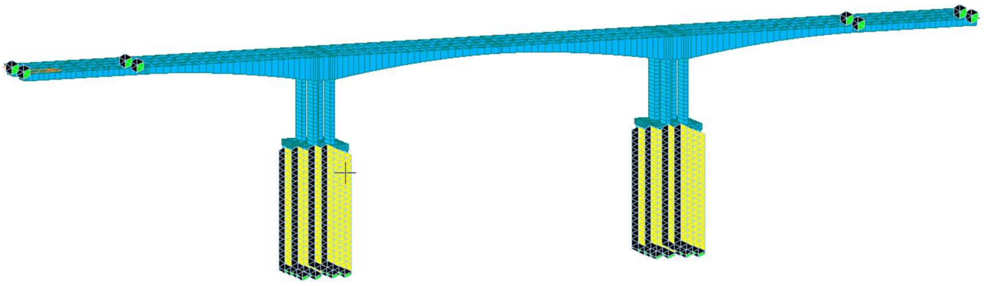
Fig. 2 Foundation structure of form two (unit: cm)

2.3 Introduction to Bridge Modelling

The finite element models of two different foundation forms of rigid-continuous combined bridge structures are established, in which the main girders, main piers and pile foundations all adopt three-dimensional beam units, and the bearing platforms (tie girders) adopt solid units, and the transverse resistance between piles and soils is simulated by applying nodal elastic support. There are 5134 nodes and 9215 units in the structural model of the whole bridge in foundation form I. There are 3272 nodes and 5516 units in the structural model of the whole bridge in foundation form II. The finite element model is shown in Fig.3.



(a) Modeling of Foundation Form I bridges



(b) Modeling of Foundation Form II bridges

Fig. 3 Finite element model of bridge structure

3. Analysis of Temperature Effects

3.1 Temperature Effect

The analysed temperature action mainly includes: system lift temperature, temperature gradient change. According to General Specification for Highway Bridge and Culverts JTG D60-2015, the temperature action load is shown in Table 1.

Table 1. Temperature-activated loads

parametric	System warm-up	system cooling	Gradient temperature rise	Gradient temperature drop
temp/℃	25	-25	T_1=14; T_2=5.5	T_1=-7; T_2=-2.25

Based on the aforementioned Mida finite element model, the stresses and displacements at the upper and lower edges of the main beams under each temperature action are compared by temperature effect analysis.

3.2 Comparison of Finite Element Analysis Structures

3.2.1 Stresses and Displacements in Main Beams under Temperature Gradients (Warming)

Fig. 4 and Table 2 show the vertical and longitudinal deformation of the main beam under temperature gradient, respectively. Among them, the horizontal coordinates of Fig. 4 represent the node numbers of the main beams, and the vertical coordinates represent the vertical displacements, with "+" indicating the upward displacements and "-" sign indicating the downward displacements. The node numbers at key locations of the model are shown in Table 2.

Table 2. Model key location node numbers

	Main girder ends	Sub-side span supports	Block 0# midpoint	main span mid-span
Node number	1, 182	26, 158	61, 123	91

From the results in Fig. 4, it can be seen that the form I centre span deflects 5.16 mm downward at mid-span position and the maximum vertical displacement in the side quarto span is 2.30 mm (upward). The maximum downward deflection in the main span of form II is 5.31mm and the maximum vertical displacement in the side span is 2.29mm (upwards).

From Table 2, it can be seen that: under the action of gradient temperature the main girder will produce the deformation of elongation along the longitudinal direction to both sides. The maximum longitudinal deformation of the main beam of Form I and Form II is equal, i.e., 4.3 mm.

In summary, the difference between the displacements of the main beams of Form I and Form II under the action of gradient temperature is very small. Among them, the effect of gradient temperature on the vertical displacement in the mid-span of the main girder of Form II is slightly larger than that of Form I, with the maximum vertical displacement differing by 0.15 mm, which is an increase of 2.9%. The vertical displacements in the mid-span of the side spans of Form I and Form II are basically equal; the longitudinal displacements of the main beams of the two foundation forms under the effect of gradient temperature are basically equal.

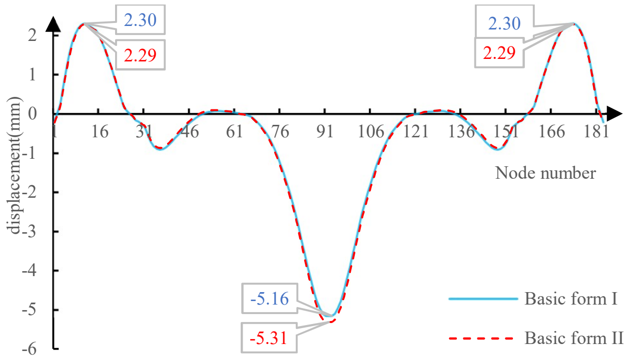


Fig 4 Vertical displacement of main beam

Table 3. Longitudinal displacement of key positions of main beam(mm)

Node number	Form I	Form II
1	-4.29	-4.30
26	-2.58	-2.59
61	-1.38	-1.38
90	0	0
123	1.39	1.38
158	2.59	2.60
182	4.30	4.31

Figs 5 to 6 show the stresses in the upper and lower edges of the main beam under the action of gradient temperature. Where, the "+" sign indicates tension and "-" indicates compression.

From Fig. 5, it can be seen that the upper edge of the main girder is compressed under the action of gradient temperature, and the stress peaks are reached at the mid-span and main pier locations. The stress curves and peak stresses at the upper edge of the two forms of main girders are basically the same, and the peak compressive stresses at the midspan and main pier of form I are 4.65 MPa and 4.67 MPa, respectively, while the peak stresses at the midspan and the main pier of form II are 4.66 MPa and 4.65 MPa, respectively.In addition to reaching the peak stress point at the midspan of the main girder, the peak stress point is reached at the 0#block of the main pier. This is due to the fact that the double-limb thin-walled pier and block 0# constitute a local superstatic structure.

From Fig. 6, it can be seen that the lower edge of the main girder is under tension, and the peak stresses are reached at the mid-span and side-span near the support. The tensile stress curves and peak tensile stresses at the lower edge of the main girder for the two forms are also basically the same, with the peak stresses at the mid-span of the mid-span and at the secondary side span near the bearing in Form I being 1.14 MPa and 0.97 MPa, respectively, and at the mid-span of the mid-span and at the secondary side span near the bearing in Form II being 1.19 MPa and 0.97 MPa.

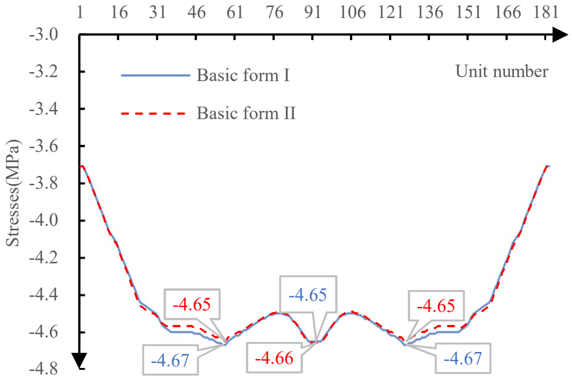


Fig. 5 stresses on the upper edge of main beam

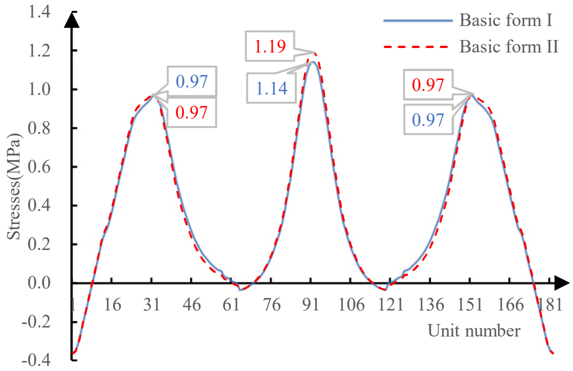


Fig. 6 stresses on the lower edge of main beam

3.2.2 Stresses and Displacements in Main Beams under Temperature Gradients (Cooling)

When the temperature gradient cooling, rigid-continuous combination of girder bridge force and system warming change rule is basically consistent, only the direction of force and displacement changes in the opposite direction.

3.2.3 Stresses and Displacements in Main Beams under System Warming Effects

Fig. 7 and Table 3 represent the vertical and longitudinal deformation of the main beam under the effect of system warming, respectively. From Fig. 7, it can be seen that the vertical displacement of the main girder is basically upward when the system is warming up. There is no vertical displacement in the girder segments of Form I and Form II side spans and part of the secondary side spans, and the maximum vertical displacement at the mid-span position of Form I is 25.28 mm, while the maximum vertical displacement at the mid-span position of Form II is 24.79 mm, which is a relatively small difference between the two. As can be seen from Table 3, after the structure is warmed up as a whole, the main girder elongates along the longitudinal direction to both ends, and the maximum longitudinal displacement of the main girder beam end of the two schemes is basically equal to that of the two schemes, which is 64.4mm.

In summary, the difference in the displacement of the main beams of Form I and Form II under the effect of systematic warming is very small. The effect on the vertical displacement in the mid-span of the main girder of Form II is slightly smaller than that of Form I. The maximum vertical displacement of the main girder of the two schemes differs by 0.49 mm, which is reduced by 1.9%. The vertical displacements of side spans and sub-side spans of Form I and Form II are basically equal; the longitudinal displacements of main beams of the two forms under the action of gradient temperature are basically equal.

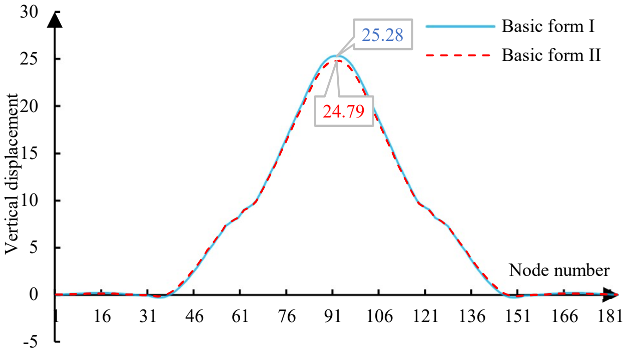


Fig. 7 Vertical displacement of main beam

Table 4. Longitudinal displacement of key positions of main beam(mm)

Node number	Form I	Form II
1	-65.34	-65.37
26	-49.30	-49.33
61	-25.60	-25.64
90	0.02	0.01
123	25.65	25.67
158	49.35	49.36
182	65.38	65.40

As can be seen from Fig. 8, under the effect of systematic warming, the stress peaks were reached at the mid-span mid-span and the mid-span upper edge of the secondary span of the main girder. The difference between the two forms of main girder upper edge stress curves is relatively small, the peak stresses at the mid-span mid-span and the mid-span upper edge of the secondary span of form I are 0.18MPa and -0.30MPa respectively; the peak stresses at the mid-span mid-span and the mid-span upper edge of the secondary span of form II are 0.17MPa and -0.28MPa respectively, in which the temperature stresses at the mid-span mid-edge location of form II are smaller than those of form I by

0.01MPa, which is a decrease of 5.6%; the upper edge stress at the mid-span location of the secondary span is 0.02 MPa less than that of Form I, a reduction of 6.7%.

As can be seen from Fig. 9, the stress peaks were also reached in the middle span of the main girder and the lower edge of the middle span of the secondary side span. The difference between the stress curves at the lower edge of the two forms of main girders is small, with the peak stresses at the lower edge of the middle span and the middle edge of the secondary span of Form I being -0.94 MPa and 0.41 MPa, respectively, and at the lower edge of the middle span and the middle edge of the secondary span of Form II being -0.92 MPa and 0.38 MPa, respectively, where the maximum stresses at the lower edge of the middle span of Form II are smaller than those in Form I by 0.02 MPa, which is a reduction of 2.1%; the maximum stress at the lower edge of the secondary span of Form II is smaller than those in Form II by 0.02 MPa, which is a reduction of 6.7%. The maximum stress at the lower edge of the middle span of the secondary span is 0.03 MPa less than that of the form I, a reduction of 7.3%.

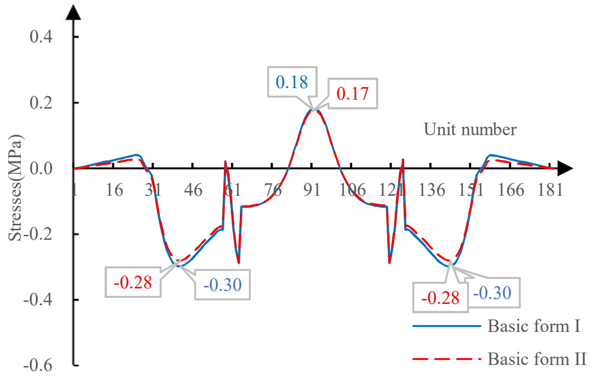


Fig. 8 stress on the upper edge of main beam

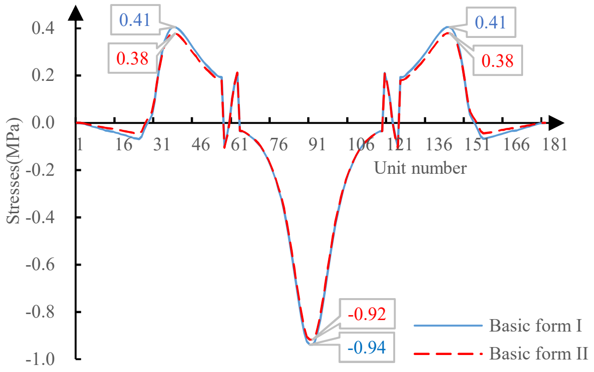


Fig. 9 stress on the lower edge of main beam

3.2.4 Stresses and Displacements in Main Beams under System Cooling Effects

When the system cools down, the force of the rigid-continuous combined girder bridge is basically the same as the change rule when the system warms up, but the direction of the force and displacement changes in the opposite direction.

4. Conclusion

This paper takes an under-construction rigid-continuous combined girder bridge in Hunan province as the engineering background, establishes the finite element model of the whole bridge with two foundation forms through MIDAS/CIVIL, and carries out the temperature effect analysis, considering the gradient temperature effect and the influence of system temperature rise and fall on the main girder line shape and upper and lower edge stresses. From the analysis, it can be seen that:

(1) When the system is warmed up, the maximum tensile stress at the upper edge of the middle span of the main girder in the middle span is reduced by 5.6% and the maximum compressive stress at the lower edge is reduced by 2.1% by adopting the foundation form II compared with form I. The maximum compressive stress at the upper edge of the middle span of the secondary side span is reduced by 6.7%. The maximum tensile stress at the lower edge of the secondary span was reduced by 7.3%, indicating that the use of Form 2 can appropriately reduce the temperature stress of the main girder under system temperature rise and fall compared with Form 1. The structural displacements of bridges with two foundation forms are basically the same under the effect of system temperature rise and fall.

(2) Under the action of temperature gradient, the difference of temperature stress of main girder of two foundation forms is small, and the displacement of main girder is basically the same.

(3) From the analysis of the temperature effect, it can be seen that the temperature gradient has the most obvious influence on the stress of the main girder, especially the main girder mid-span span and the upper edge position at the side span support produced a large compressive stress (4.7MPa). As the double-limb thin-walled pier and block 0 constitute a local superstatic structure, large stresses are generated under the effect of temperature difference, which is very unfavourable to the structure. Gradient temperature has less influence on the main girder line shape, the main girder under the action of temperature gradient elongates along the parabridge direction, and the vertical displacement of the main span of the main girder develops downwards as a whole, showing a downward concave tendency, while the continuous girder section shows an upward convex tendency. And the system lift temperature mainly affects the line shape of the main girder, due to the constraints of the abutment makes the main girder produce larger vertical deformation. Therefore, for large-span continuous rigid bridge, the temperature difference effect of the bridge structure should be paid enough attention in the engineering calculation.

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