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RESEARCH ON OPTIMAL CLOSURE PROCESS OF CONTINUOUS RIGID FRAME BRIDGE

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Abstract: The closure process of the continuous rigid frame bridge influences the bearing capacity and displacement of structures after completion. In this article, the effects of different closure processes on bridge internal forces and displacements have been researched by analyzing the three-span continuous rigid bridge with the finite element analysis software. And to the continuous rigid frame bridge with unequal height piers, the changing differences of its internal forces and displacements have been compared in terms of applying the same joint scheme. Ultimately, the optimal joint scheme of continuous rigid frame bridge with equal and unequal height piers at closure construction has been obtained.

Keywords: Continuous Rigid Frame Bridge; Closure Process; Internal Force and Displacement

1. Introduction

In the cantilever construction process, the selection of closure process is a very important part due to the structure system transformation, namely the structure form converts from statically determinate structure to statically indeterminate structure. Different closure processes have various effects on bridge internal force and displacement, different demand for the difficult degree of construction, manpower and equipment. Furthermore, the closure process is significant to construction organization and progress control as it has a great impact on the construction duration and cost.

Therefore, before the project construction, each closure process should be analyzed theoretically and compared with each other so that to select the optimal combination of structural internal force, displacement and the difficult degree of construction. Thus, the greatest social and economic benefits can be achieved.

In this article, the effects of different closure processes on bridge internal force and displacement have been researched by analyzing the three-span continuous rigid bridge with setting up the finite element model. And the differences of internal force and displacement have been made a comparison in the case of applying the same joint scheme to the continuous rigid frame bridge with unequal height piers. Thus, the optimal joint scheme of continuous rigid frame bridge with different types has been obtained.

2. Optional Joint Scheme

Basing on the cantilever construction of three-span continuous rigid bridge, there are four typical closure processes as follows:

(1) Symmetric closure of the two side spans - closure of mid span, abbreviated to S1;

(2) Closure of one side span - closure of mid span - closure of the other one side span, abbreviated to S2;

(3) Simultaneously disposable closure of all spans, abbreviated to S3;

(4) Closure of mid span - Symmetric closure of the two side spans, abbreviated to S4.

The above four joint schemes have their own advantages and disadvantages. When adopting the S1 and S4, the construction speed is fast for the symmetric construction with two working faces. In the S2, the structure owns good entirety during the construction because the T-shape would become an entirety with each one section closured. The construction speed of the S3 is the fastest, but uneconomical for the needs of manpower and equipment are largest. In the specific engineering practice, that adopting which scheme should be selected through the construction management, considering the bridge bearing capacity and displacement comprehensively, and combining with the requirements of funds and duration.

3. Establishment of Finite Element Model

The Second Huaihe River highway bridge is located near the South Lake Avenue outside the Fengtai County's main districts. The superstructure of the main bridge is a continuous rigid-frame with (97m+176m+97m) long and 15.95m wide. The beam section form is single box with double chambers. The change of beam depth is in accordance with the cubic parabola (side span 4m — zero block 10m — mid-span 4m).

Establishing the finite element model in order of the construction sequence by the bridge design and calculation software of MIDAS/CIVIL. Choosing which closure process would be embodied in the construction phase of finite element simulation. The main girder, main pier and bearing platform are divided into 128, 56 and 4 units respectively. The boundary conditions are pier-beam rigid connection, pier-bearing platform rigid connection and the bottom of the cushion cap consolidation. The loads include the dead weight, the pre-stressed load, after-crop permanent load, hanging basket load and temperature load. As illustrated in Fig.1. To add 11000 days (about 30 years) for considering the impact of concrete shrink-creep.

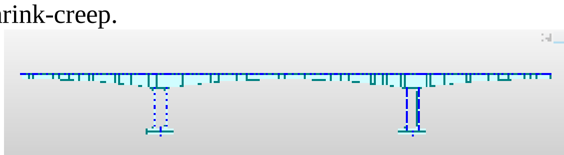

Figure1. The finite element model of the Second Huaihe River highway bridge

4. Comparison of Structure Internal Force and Displacement

4.1. Continuous Rigid Frame Bridge with Equal Height Piers

When applying these four joint schemes to the closure construction of the Second Huaihe River highway bridge, the changes of internal forces and displacements in bridge finished state and after 30 years are shown in table 1 and table 2. The trend graphs of several internal forces are illustrated in Fig.3 and Fig.4. Due to the layout of the bridge is symmetric form, taking the left part of the bridge as representative to analyze. As shown in Fig.2:
a: the bottom of cushion cap; b: half of the left pier shaft; c: half of the right pier shaft; d: left pier-top; e: right pier-top; f: zero block; g: half of the side span; h: mid-span.

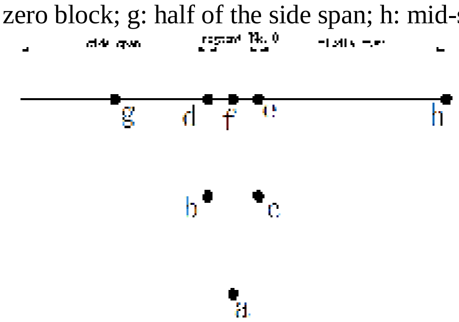

Figure 2. The simple model of the left part

Table 1. Changes of internal forces of each control section (KN*m)

Phase	Joint scheme Control section	S1	S2	S3	S4
bridge finished state	A	2.27E+05	4.55E+05	2.16E+05	2.13E+05
	B	8.68E+02	1.77E+03	8.23E+02	7.57E+02
	C	2.15E+03	3.09E+03	2.09E+03	2.02E+03
	D	-3.06E+04	-7.89E+04	-2.89E+04	-3.12E+04
	E	-1.88E+04	-6.68E+04	-1.76E+04	-1.93E+04
	F	-2.22E+06	-2.23E+06	-2.22E+06	-2.22E+06
	G	-3.30E+05	-3.46E+05	-3.29E+05	-3.38E+05
	H	2.27E+05	2.34E+05	2.29E+05	2.28E+05
after 30 years	A	2.13E+05	4.38E+05	2.05E+05	2.04E+05
	B	8.68E+02	1.76E+03	8.22E+02	7.57E+02
	C	1.92E+03	2.83E+03	1.87E+03	1.82E+03
	D	-2.88E+04	-7.66E+04	-2.76E+04	-2.94E+04
	E	-1.88E+04	-5.66E+04	-1.76E+04	-1.93E+04
	F	-4.87E+05	-4.96E+05	-4.85E+05	-4.91E+05
	G	-3.81E+04	-5.29E+04	-3.76E+04	-4.33E+04
	H	9.07E+03	1.48E+04	1.11E+04	1.12E+04

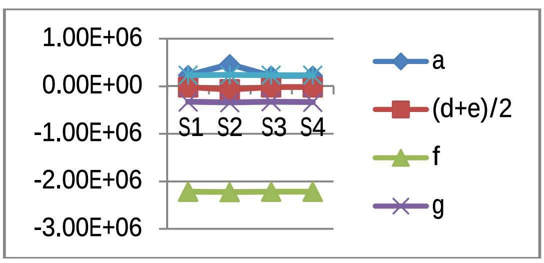

Figure 3. Changes of internal forces of each control section in bridge finished state

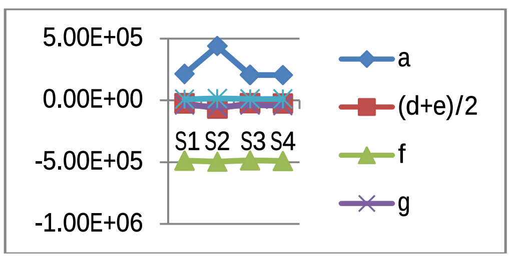

Figure 4. Changes of internal forces of each control section after 30 years

From the above charts, the conclusions can be drawn:

(1) Making the comparison of each index according to the bridge completion time. From the bridge finished state to 30 years later, the bending moment of each pier control section has reduced slightly while the bending moment of each beam control section is significantly increasing.

(2) Making the comparison according to the joint scheme. In S1, S3 and S4, the bending moment of the same control section is very close no matter in the bridge finished state or 30 years later. On the contrast, the bending moment in S2 is larger than the other three, especially in the bottom of cushion cap, half of the pier shaft and pier-top, the values are two times or more than the other. The bending moment of the zero block, half of the side span and the mid-span is slightly larger than the other three in the bridge finished state, but after 30 years, the values also increase to about 1.5 times of the other.

Then compare the displacements of each control section. Due to the displacements of the cushion cap bottom are always zero, there is no need to compare it anymore.

Table 2. Changes of displacements of each control section (m)

Phase	Joint scheme Control section	S1	S2	S3	S4
bridge finished state	b	2.25E-03	2.05E-03	2.38E-03	2.71E-03
	c	5.13E-03	5.73E-03	4.88E-03	4.39E-03
	d	3.81E-03	4.17E-03	3.74E-03	3.89E-03
	e	6.72E-03	7.73E-03	6.29E-03	5.49E-03
	f	3.37E-03	4.13E-03	3.05E-03	2.78E-03
	g	1.097E-01	1.097E-01	1.095E-01	1.082E-01
	h	4.54E-02	4.88E-02	4.40E-02	4.13-02
after 30 years	b	1.75E-02	4.3E-02	1.67E-02	1.77E-02
	c	1.41E-02	3.9E-02	1.34E-02	1.43E-02
	d	3.64E-02	8.93E-02	3.48E-02	3.66E-02
	e	3.13E-02	8.36E-02	2.97E-02	3.14E-02
	f	3.71E-02	9.23E-02	3.53E-02	3.69E-02
	g	7.25E-02	1.15E-01	7.17E-02	7.45E-02
	h	4.59E-02	7.67E-02	5.18E-02	4.77E-02

From the table of displacement changing:

(1) In these four joint schemes, the overall trend of each control section displacements is increasing from the bridge finished state to 30 years later. The displacements of each pier control section and zero block increase significantly, and the mid-span have a slightly increasing. However, what needs to be pointed out is the half of the side span. The displacement increases in S2 from the bridge finished state to 30 years later while decreases obviously in the other three, and the ultimate value fall to about half of the initial.

(2) In the bridge finished state, the displacements of the same control section are very close in these four joint schemes. After 30 years, the values still have no much difference in S1, S3 and S4 while have increased more than twice times than the other three in S2.

Obviously, S2 is not applicable to the closure construction of the equal high pier continuous rigid frame. The internal forces and displacements of the other three are relatively close, and within the reasonable range so that the S1, S3 and S4 can be alternatives to closure construction.

Continuous rigid frame bridge with unequal height piers

The continuous rigid frame bridge model with unequal height piers is set up by keeping other conditions unchanged and only changing the original bridge pier height. The simple model is illustrated in Fig.5. The changes of internal forces and displacements in different joint schemes have been discussed in the case of different pier height ratio for 2:1 and 3:1.

As the demonstration in 3.1 above, the S2 has not been taken into account in the following comparison because of not applicable to the three-span continuous rigid frame construction. The displacements of the cushion cap bottom are always zero, no need to list in the tables.

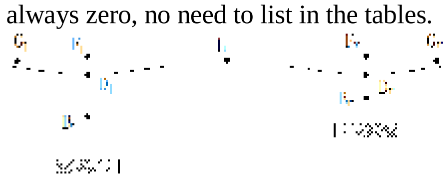

Figure 5. The simple model

h: mid-span; G is the half of the side span; F is the zero block; D is the pier-top; B is the half of pier shaft. The meaning of subscript index l and r is left and right.

In the case of pier height ratio of 2:1, the changes of internal forces and displacements of each control section are shown in table 3 and table 4.

In the case of pier height ratio of 3:1, the changes of internal forces and displacements of each control section are shown in table 5 and table 6.

Table 3. Changes of internal forces of each control section (KN*m)

Phase	Joint scheme Control section	S1	S3	S4
bridge finished state	B_l	1.87E+03	1.79E+03	1.78E+03
	B_r	6.29E+02	5.39E+02	7.56E+02
	D_l	-4.59E+04	-4.40E+04	-4.66E+04
	D_r	2.24E+04	2.16E+04	2.28E+04
	F_l	-2.22E+06	-2.22E+06	-2.23E+06
	F_r	-2.22E+06	-2.22E+06	-2.23E+06
	G_l	-3.28E+05	-3.35E+05	-3.41E+05
	G_r	-3.36E+05	-3.28E+05	-3.32E+05
	h	2.28E+05	2.30E+05	2.30E+05
after 30 years	B_l	1.74E+03	1.68E+03	1.67E+03
	B_r	7.65E+02	7.04E+02	8.74E+02
	D_l	-4.42E+04	-4.30E+04	-4.51E+04
	D_r	2.05E+04	1.98E+04	2.09E+04
	F_l	-4.88E+05	-4.85E+05	-4.90E+05
	F_r	-4.88E+05	-4.88E+05	-4.90E+05
	G_l	-4.38E+04	-4.31E+04	-4.72E+04
	G_r	-3.41E+04	-3.45E+04	-3.68E+04
	h	1.00E+04	1.18E+04	1.22E+04

Table 4. Changes of displacements of each control section (m)

Phase	**Joint scheme Control section**	**S1**	**S3**	**S4**
bridge finished state	B_l	4.0E-03	4.0E-03	4.0E-03
	B_r	2.5E-03	2.5E-03	2.0E-03
	D_l	6.5E-03	6.0E-03	5.0E-03
	D_r	3.0E-03	3.0E-03	3.0E-03
	F_l	5.0E-03	4.0E-03	3.0E-03
	F_r	1.0E-03	1.0E-03	1.0E-03
	G_l	1.11E-01	1.10E-01	1.09E-01
	G_r	1.09E-01	1.09E-01	1.09E-01
	H	4.3E-02	04.2E-02	4.0E-02
after 30 years	B_l	2.7E-02	2.6E-02	2.7E-02
	B_r	6.0E-03	5.0E-03	6.0E-03
	D_l	5.7E-02	5.5E-02	5.7E-02
	D_r	1.0E-02	9.0E-03	1.0E-02
	F_l	6.1E-02	5.9E-02	6.1E-02
	F_r	1.2E-02	1.1E-02	1.2E-02
	G_l	8.9E-02	8.8E-02	9.1E-02
	G_r	5.7E-02	5.7E-02	5.8E-02
	H	5.2E-02	5.6E-02	5.4E-02

Table 5. Changes of internal forces of each control section (KN*m)

Phase	Joint scheme Control section	S1	S3	S4
bridge finished state	B_l	1.91E+03	1.83E+03	1.83E+03
	B_r	-7.16E+03	-7.02E+03	-7.15E+03
	D_l	-4.98E+04	-4.80E+04	- 5.06+04
	D_r	1.51E+04	1.45E+04	1.55E+04
	F_l	-2.22E+06	-2.22E+06	-2.23E+06
	F_r	-2.18E+06	-2.18E+06	-2.18E+06
	G_l	-3.37E+05	-3.36E+05	-3.42E+05

	G_r	-3.24E+05	-3.25E+05	-3.28E+05
	h	2.28E+05	2.30E+05	2.30E+05
after 30 years	B_l	1.79E+03	1.72E+03	1.72E+03
	B_r	-6.57E+03	-6.45E+03	-6.57E+03
	D_l	-4.80E+04	-4.68E+04	-4.89E+04
	D_r	1.48E+04	1.44E+04	1.51E+04
	F_l	-4.87E+05	-4.84E+05	-4.88E+05
	F_r	-4.51E+05	-4.52E+05	-4.54E+05
	G_l	-4.46E+04	-4.38E+04	-4.77E+04
	G_r	-3.11E+04	-3.16E+04	-3.36E+04
	h	9.78E+03	1.15E+04	1.19E+04

Table 6. Changes of displacements of each control section (m)

Phase	Joint scheme Control section	S1	S3	S4
bridge finished state	B_l	4.0E-03	4.0E+03	4.0E+03
	B_r	1.0E-03	1.0E-03	1.0E-03
	D_l	7.0E-03	6.0E-03	5.0E-03
	D_r	2.0E-03	2.0E-03	2.0E-03
	F_l	5.0E-03	4.0E-03	3.0E-03
	F_r	1.0E-03	1.0E-03	1.0E-03
	G_l	1.11E-01	1.1E-01	1.09E-01
	G_r	1.09E-01	1.09E-01	1.09E-01
	h	4.3E-02	4.2E-02	4.0E-02
after 30 years	B_l	2.9E-02	2.8E-02	2.9E-02
	B_r	3.0E-03	2.0E-03	2.0E-03
	D_l	6.1E-02	5.9E-02	6.1E-02
	D_r	6.0E-03	6.0E-03	6.0E-03
	F_l	6.5E-02	6.3E-02	6.6E-02
	F_r	7.0E-03	7.0E-03	7.0E-03
	G_l	9.3E-02	9.1E-02	9.4E-02
	G_r	5.6E-02	5.6E-02	5.6E-02
	h	5.3E-02	5.6E-02	5.5E-02

From the above data, it can be obtained that when applying the S1, S3 and S4 to closure construction of the unequal high pier continuous rigid frame, the bending moment and displacements of the same control section in very close no matter in the bridge finished state or 30 years later. These three joint schemes are applicable to the closure construction of continuous rigid frame.

5. Conclusions and Recommendations

In S2, the structure internal forces and displacements are much larger than the other three. visibly it is not applicable to the closure of three-span continuous rigid frame bridge construction.

(2) When applying S1, S3 and S4 to closure construction of the equal and unequal high pier continuous rigid frame, the structure internal forces and displacements of the same control section are very close. Therefore, these three schemes can be the alternatives expanded to other continuous rigid frame construction.

(3) Since only researching the closure schemes of the three-span continuous rigid frame bridge in this article, so the conclusions own certain limitations.

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