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Calculating the closure jacking-force of a large-span pre-stressed concrete continuous rigid frame bridge

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ABSTRACT
Before closuring the mid-span of a large-span pre-stressed concrete continuous rigid frame bridge, imposing jacking-force could commendably eliminate the down-warping of main beam, horizontal deviation of main pier and the additional internal force caused by temperature differential and concrete shrink-creep. Two formulas deduced in this article to calculate the jacking-force have been applied to an engineering example to analyze and compare their applicability by combining with finite element simulation. The results showed that both formulas were practicable and could be as a simple computational method extended to other bridges with the same type.
***Keywords* -** bridge, closure, continuous rigid frame bridge, jacking-force

I. INTRODUCTION

The continuous rigid frame bridge is widely used in modern bridge construction for the advantages of strong crossing competencies, good entirety, driving comfort and attractive outlook. Moreover, with the mature construction technology, rational project cost, it has a strong competitiveness among bridges with the main span between 100 and 300 meters.

However, this bridge type is statically indeterminate structure, the temperature changes and concrete shrink-creep will cause additional internal force in the structure. Moreover, during the stage of constructing the closure segment, the actual temperature may not match the design value. This temperature differential will cause displacement of beam. Similarly, the concrete shrink-creep will cause the beam deflected vertically and shifted horizontally. Due to the pier-beam fixed form of continuous rigid-frame, the main pier would deviate to the mid-span while the beam deflected. And the displacement will result in generating secondary stress in the bridge structure which is particularly greater in the pounding bottom. These adverse states not only impact on the driving comfort and aesthetic, but also work against to the carrying capacity of pier.

In order to improve these situations, the construction method of imposing jacking-force on the cantilever end of closure section, which could give the main pier a preliminary reverse displacement, can be implemented. Two mathematical formulas to express the relationship between the jacking-force and the horizontal displacement have been deduced on the base of structural mechanics. Combining the formulas with a finite element model of engineering example, how to confirm the jacking force of continuous rigid frame bridge has been studied in this article.

II. DERIVATION OF THE FORMULAS

Basing on a three-span continuous rigid frame, two formulas for jacking dorce calculation have been deduced.

1.1 Statically indeterminate structure

The simplified model of a continuous rigid frame bridge with double thin-wall piers is illustrated in Fig.1. It is in the phase of mid-span closure. P is the closure jacking force and Pe (e is the vertical distance from P to centroid of the cross section) is a eccentric bending moment caused by P as its point of application could not be in a straight line with the centroid of box section during the construction. Taking the left section of the bridge as a basic structure which is three-fold statically indeterminate. As shown in Fig.2.

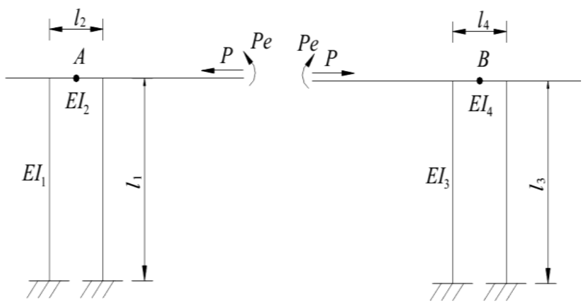


figure1: the simplified model

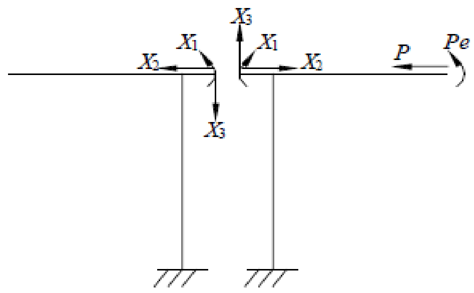
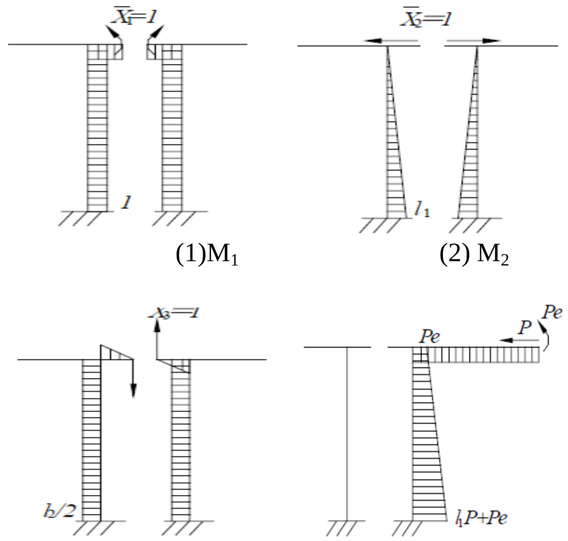


figure2: the basic structure

Establishing the compatibility equation of force method:

$$\begin{cases}\delta_{11}X_1+\delta_{12}X_2+\delta_{13}X_3+\Delta_{1p}=0\\ \delta_{21}X_1+\delta_{22}X_2+\delta_{23}X_3+\Delta_{2p}=0\\ \delta_{31}X_1+\delta_{32}X_2+\delta_{33}X_3+\Delta_{3p}=0\end{cases} \quad (1)$$

The bending moment diagrams of the basic structure under the action of each force are shown in Fig.3.



(1)M_1 (2) M_2

(3)M_3 (4) M_p

figure3: the bending moment diagrams

Because X1 and X2 are symmetric forces, X3 is anti-symmetric force, so the parameters. By using the graphic multiplication method, each parameter is worked out as follows:

$$\begin{cases}\delta_{11}=2l_1/EI_1+l_2/EI_2\\ \delta_{22}=2l_1^3/3EI_1\\ \delta_{33}=l_1l_2^2/2EI_1+l_2^3/12EI_2\\ \delta_{12}=\delta_{21}=l_1^2/EI_1\end{cases}$$

$$\begin{cases}\Delta_{1p}=-(2el_1+l_1^2)P/2EI_1\\ \Delta_{2p}=-(3el_1^2+2l_1^3)P/6EI_1\\ \Delta_{3p}=-(2el_1l_2+l_1^2l_2)p/4EI_1\end{cases}$$

The stiffness of zero block is much larger than the thin-wall pier, therefore it can be assumed the stiffness of zero block for infinity ($EI_2 \propto \infty$). Substituting these parameters in the formula (1), the outcome is as follows:

$$\begin{cases}X_1=Pe/2\\ X_2=P/2\\ X_3=(2e+l_1)P/2l_2\end{cases}$$

Basing on the principle of superposition, the bending moment of the simplified model is M=M1+M2+M3+Mp

According to the principle of virtual work force and displacement are independent and unrelated[1], it can be assumed that point A of the basic structure bore a horizontal unit virtual force (FA=1) on the premise that all the redundant unknown forces were worked out. And because the displacement of rigid frame is mainly dominated by the bending moment, so the value can be obtained on the basis of displacement calculation formula:

$$\Delta_{AX}=\sum\int MM_A d_s/EI_1$$
$$=[l_1^2Pe/4+l_1^3P/6-(l_1^3+2el_1)P/8]/EI_1$$
$$=l_1^3p/24EI_1$$

Cosh x:

$$\Delta_{BX}=\sum\int MM_B d_s/EI_3=l_3^3p/24EI_3$$

The relative displacement of two piers:

$$\Delta_{AB}=\Delta_{AX}+\Delta_{BX}=l_1^3p/24EI_1+l_3^3p/24EI_3$$

The calculation formula of the jacking force:

$$P=24EI_1I_3\Delta_{AB}/(I_3l_1^3+I_1l_3^3) \quad (2)$$

1.2 Statically indeterminate structure

Due to the stiffness of zero block is much larger than the thin-wall pier, the statically indeterminate structure can be simplified to a statically indeterminate structure with single thin-wall pier. The practical jacking force to cause is 1/2p [2]. The simplified model of the single thin-wall pier structure is illustrated in Fig.4.

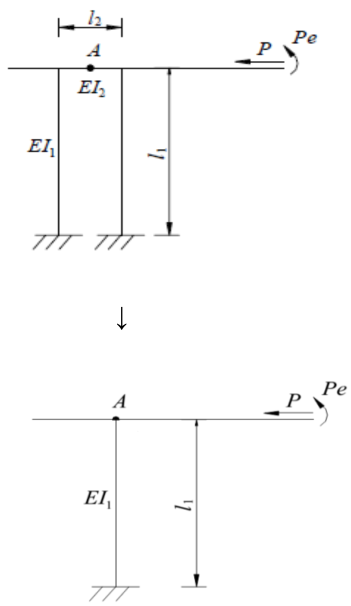
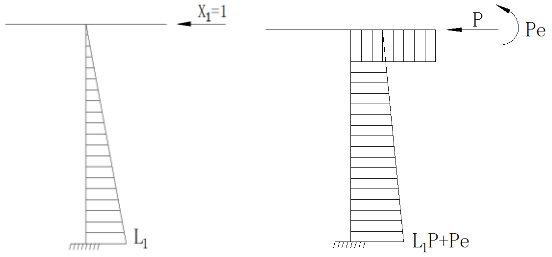


figure4: the simplified model (2)

The bending moment diagrams are shown in Fig.5.



(1)M_1' (2) M_p'

figure5: the bending moment diagrams (2)

Basing on the displacement calculation formula, the calculation formula of offset value:

$$\Delta_{AX}^{'} = \sum\int MM_A d_s/EI_1 = (3el_1^2 + 2l_1^3)p/12EI_1$$

Cosh x:

$$\Delta_{BX}^{'} = (3el_3^2 + 2l_3^3)p/12EI_3$$

The calculation formula of the jacking force:

$$p = 12EI_1I_3\Delta_{AB}^{'}/[I_3(3l_1^2e + 2l_1^3) + I_1(3l_3^2e + 2l_3^3)] \quad (3)$$

III. ESTABLISHMENT OF FINITE ELEMENT MODEL AND CALCULATION OF THE HORIZONTAL DISPLACEMENT

The Huaihe River highway bridge is located near the South Lake Avenue outside the main districts of Fengtai County. The main bridge superstructure is continuous rigid-frame of 370m (97m+176m+97m) long, 15.95m wide. The beam section is single box with double chamber. The change of beam depth is in accordance with cubic parabola (side span 4m——zero block 10m——mid-span 4m). Construction method of this bridge is symmetrical cantilever construction. Constructing in the sequence of firstly pouring cantilevers symmetrically, then closuring the mid-span, finally the side span.

The finite element model is established in order of the construction sequence by bridge design and calculation software MIDAS/CIVIL8.0. Its main girder and main pier are divided into 128 and 56 units respectively, the boundary conditions are pier-beam consolidation and the bottom of the pier consolidation. As illustrated in Fig.6. To add 10000 days for considering the impact of concrete shrink-creep. Setting the temperature difference between actual temperature and design value is 3℃. By using the software calculation, the horizontal displacement of both main piers can be given.

The displacement of pier 2: $\Delta_{AX} = 3.79$cm

The pier 3: $\Delta_{BX} = -3.79$cm (Taking the right as the positive direction)

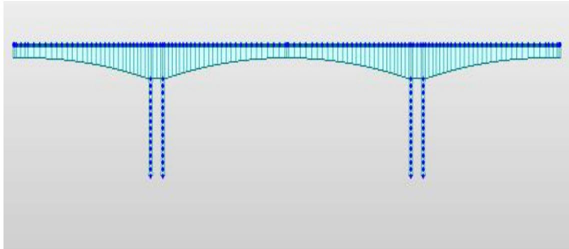


figure6: the finite element model

IV. CONFIRMATION OF JACKING FORCE

In the real construction process, it can symmetrically apply the jacking force to the tapered haunch as it cannot be loaded directly in the centroid of box section. P·e is an additional eccentric bending moment to the centroid. Using the computerization software to calculate, the horizontal jacking force aroused by the forced displacement $\Delta_{AX}(= -3.79\text{cm})$ is 7431 (KN).

According to formula (2), the jacking force:

P =

$12EI_1\Delta_{AB}/l_1^3$ =12×3.25×107×5.32×0.0379×2/283=7164 (KN)

According to formula (3), p=8411(KN)

V. ANALYSIS OF THE CALCULATING RESULTS

In the situation of different jacking force, to compare the displacements of pier 1 calculated by analytical formulas and finite-element analysis (FEA). As shown in table 1.

Table 1: the displacements calculated in 3 methods

The jacking force/(KN)	FEA/(cm)	Statically in-determinate structure/(cm)	Statically determinate structure/(cm)
2000	1.02	1.06	0.9
4000	2.06	2.12	1.8
6000	3.05	3.17	2.7

From the table, it can be observed the displacements calculated by both analytical formulas and FEA are similar. Comparing the changes of structure additional internal forces in case of imposing the jacking force and not. As shown in table 2.

Table 2: the stress of each control section (KN·m)

Major control sections	Without jacking force	Imposing jacking force (2)	Imposing jacking force (3)
Bottom of pier 1	1.94E+05	-7.56E+03	-4.8E+04
The middle span section	2.05E+04	1.76+03	1.2E+03

It is thus evident that the internal force of the control sections has been substantially improved after imposing the jacking force. The effect of optimizing the stress performance has been obtained.

VI. CONCLUSION

1) From these two analytical formulas for calculating the jacking force, the conclusion jacking force is linear with displacement can be drawn. And the calculated results prove that the theoretical calculating values match well with the values from finite element calculation. These two formulas can be extended as a simple computational method to other bridges with the same type.
2) However, in the process of deducing, only the effects of bending moment on pier displacement were considered, the effects of axial force and shearing force had been ignored. Consequently, the formulas exists certain errors. That the stiffness of zero block was assumed to infinite also has some influence on computational accuracy for it is impossible in practical engineering.
3) According to the results from table 1 and table 2, during the closure segment construction of large-span pre-stressed concrete continuous rigid frame bridge, imposing jacking-force properly to give the pier a pre-displacement could effectively counteract the pier offset and improve the stress performance of the bridge.

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