

## A Study on the Controlling Method of the Statically Indeterminate Bridge's Additional Internal Force Caused by the Temperature Action

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**Abstract.** The secondary internal force caused by temperature in statically indeterminate bridges are usually huge, sometime is the control factor in bridge design. Since the temperature investigation of bridge construction site is difficult to predict, there deviation between design joining temperature and actual temperature and the leaded secondary internal force is inevitable. Based on this, an adaptive temperature internal force control method is proposed. This method utilizes a pre-set steel cable. When the environmental temperature changes produce negative effects to the structure, the additional force and moment of cable with the change of environment temperature will offset the effect. This method can be widely used in the temperature internal force control of statically indeterminate bridge structures, and can effectively reduce the additional internal force of undetermined bridge structures caused by temperature differences.

### Introduction

The impact of environmental temperature on the bridge is the common and the internal force and deformation caused by temperature will affect the serviceability and safety of bridges. Since the latter half of the twentieth Century, serious damage accidents have been found due to the temperature stress caused by concrete structure deterioration all over the world. J. Zhou [1] have surveyed reinforced concrete rib arch bridge with the span over 50m and found that the crack in arch rib, arch foot and the bottom of middle span has become one of the typical disease of the bridge. Q. Zhang [2] also found that, main arch vault transverse cracking has become one of the typical disease of box arch bridge. Severe cracking occurred in Jagst thick web box girder bridge in Germany after opened to traffic for five years, and the temperature tensile stress is estimated as high as 2.6MPa [3].

G. Yin [4] and Z. Fang [5] used different model to predict the temperature variation of bridges. Fritz Leonhardt draw the conclusion that the temperature difference between the surface and the bottom of the box girder bridge and the slab bridge is 27~33°C. After field test observation and theoretical study of severe cracking of several prestressed concrete box girder bridges. In the design of bridge, it is a common understanding that the temperature effect (uniform temperature and temperature gradient) should be considered [6]. However, accurately considering the influence of environmental temperature

will be impossible in the design of bridge structures [7]. Thus, the author puts forward an active and adaptive control method for temperature internal force in statically indeterminate bridge structure. Based on this concept, this paper introduces the background, main ideas and principles of the proposed method, although the concrete feasibility demonstration and engineering application is still need further research.

### Temperature internal force of Statically Indeterminate Structure and its hazard

The large span statically indeterminate structure is mainly influenced by temperature. For some bridges, the temperature effect is even more than the design live load effect[8]. The temperature effect has been considered as one of the main reasons for the cracks of concrete bridges. For example, a main span of  $3 \times 100\text{m}$  upper deck concrete arch bridge, the temperature effect in some cross section is even more than the vehicle live load effect (as shown in Fig. 1, Fig. 2).

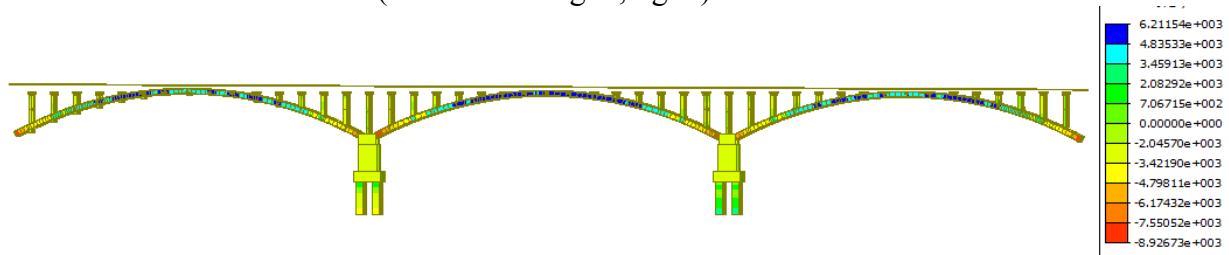


Fig.1 Vehicle load moment(My,units:kN · m)

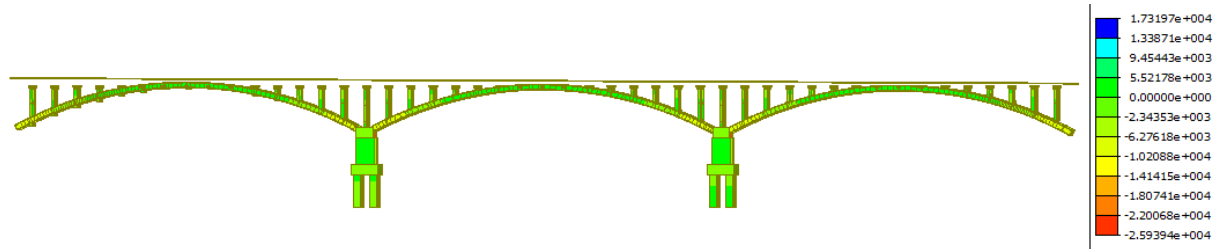
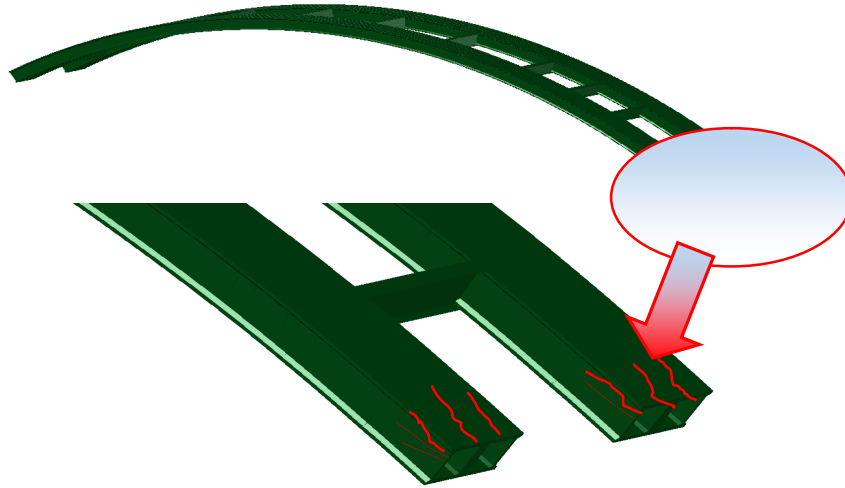


Fig.2 Moment after 10℃ dropping(My,units:kN · m)

When the ambient temperature changes, the arch will produce temperature deformation due to the arch of the material thermal expansion and contraction properties; When the deformation is constrained, the arch will produce considerable additional temperature stress. Generally, temperature decreasing will lead to a negative moment of the arch foot of the non-hinged arch bridge. The arch crown has a positive moment, resulting in the cracking of the arch foot and the lower part of the arch crown. Therefore, temperature decreasing is usually unfavorable for the non-hinged arch bridge. In recent years, through the detection of the real bridge, it has been found that a large number of box non-hinged arch bridge whose upper edge of arch foot section and the lower edge of the middle section has this disease and this also confirmed the point above(as shown in Fig.3).

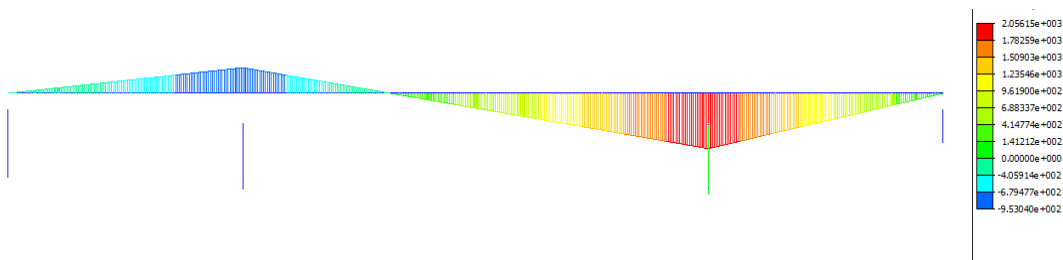


**Fig.3 The sketch map of arch foot cracking disease**

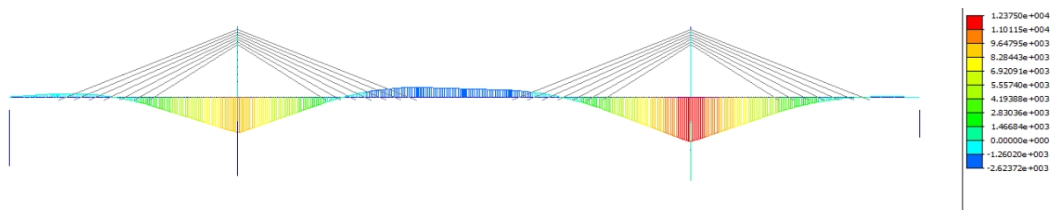
Based on this, how to adaptively reduce or even eliminate the temperature decreasing of the adverse impact of the non-hinged arch bridge, has already become an important concern of this kind of bridge diseases and the retrofit of it.

### An adaptive control measure

Temperature internal force appears since the freedom and expansion caused by the change of environment temperature is restricted. By this inspiration, if there is additional material of free expansion of the bridge is the main force of the constraint, then in the environment temperature, there will be an additional temperature force applied to the bridge. If the additional force is just able to offset the adverse effect caused by temperature effect, it can achieve the effect of adaptive control. Based on this, we first investigate the internal force of continuous girder bridge and cable stayed bridge in the same temperature condition. As shown in Fig.4 and Fig.5, the bending moment distribution of the continuous girder bridge and cable-stayed bridge of the same span arrangement (90+180+90m) under the same temperature condition is not the same. This is mainly due to the arrangement of the stay cables. In the case of temperature decreasing, the shrinkage of the stay cables has a positive effect on the main beam.



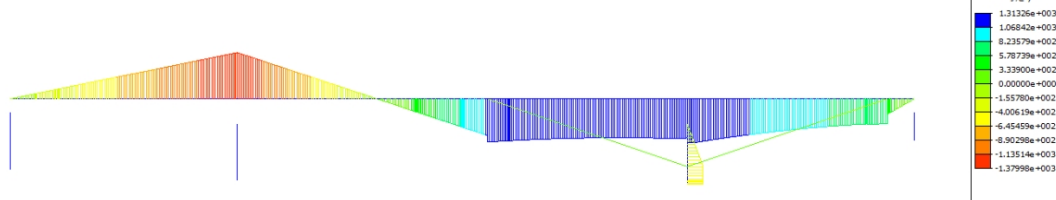
**Fig.4 Temperature internal force diagram of continuous girder bridge(My,units:kN · m)**



**Fig.5 Temperature internal force diagram of cable stayed bridge(My,units:kN · m)**

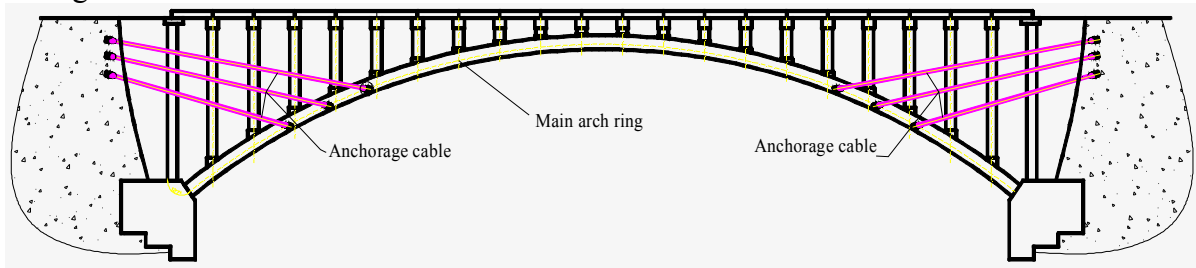
For continuous girder bridges, self-weight and other live load effect cause the main girder to generate negative bending moment near the bridge pier. Based on the above analysis, the arrangement of cables in the cable-stayed bridge will make the main beam produce a large positive moment in the temperature decreasing condition, from Figure 5, the cable can effectively resist the adverse effects of

environment temperature decreasing on main girder. That is, if there is no cable force in the cable-stayed bridge, and not to make it become a cable-stayed bridge, and the stay cable only works when temperature decreases. The arrangement of the cable plays a role in resisting the environment temperature decreasing. Of course, if only in order to resist the temperature effect and layout so much of the cable is not economical. In order to further understand the influence of the different structure of the cable layout in the environment temperature difference, we set up a pair of stayed cables on the pier of the continuous beam, which can be seen from Fig. 6. The positive bending moment caused by temperature decreasing in the pier is reduced by about 35%.



**Fig.6 The case of the lower part of the cable(My,units:kN · m)**

Similarly, for the non-hinged arch bridge, when negative moment is generated at the arch foot in the case of the environment temperature decreasing, the tension of the cable is affected by temperature, which can product positive moment of the arch foot and partially offset the additional bending moment due to the environment temperature decreasing(As shown in Fig.7). Stay cables only play a role in the structure under the temperature decreasing effect, in the case of heating, automatically separated with arch bridge.



**Fig. 7 A sketch map based on the measure of the non-hinged arch bridge**

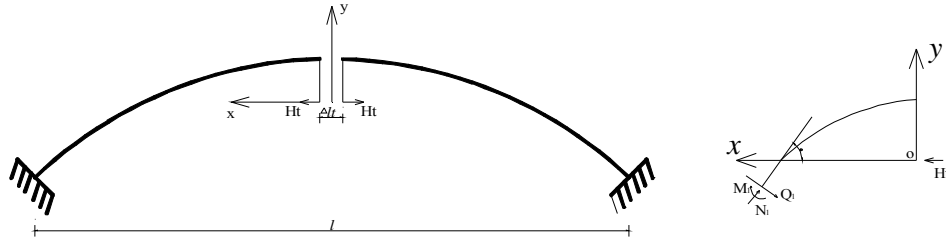
When the ambient temperature decreases, the cable can shorten and product the pulling force, the bending moment can be reduced or even completely offset the adverse effect caused by temperature rise (or decrease). The cable is made of high strength steel wire rope. Cable diameter is determined according to the span of the structure, design temperature parameters. The anchorage position is determined according to the requirement, for example, hingeless arch bridge can be anchored to the main arch of 1/8~3/8 interval, the other end anchored on the side wall of abutment or for anchoring structures. According to the needs, we can layout 1 or more cables. Cable installation emphasizes the tension mounted on the ratio of indeterminate closure temperature above, in this case, you can reserve a certain temperature difference in advance. When temperature decreases, the cable tension inside will be greater, the effect is more obvious. The installation of cable is 10 degrees Celsius above the closing temperature, this takes temperature decreasing into account. Similarly, if heating up is negative in a part of the statically indeterminate structure, the situation is opposite.

To investigate the effect of the method, we use constant section catenary non-hinged arch bridge as an example(as shown in Fig.8). Calculation of internal temperature in the non-hinged arch bridge:

If the temperature change caused by the arch axis in the horizontal direction variable bit for  $\Delta l_t$ , and the elastic compression for the same reason, must be a pair of horizontal force is generated in the elastic center:

$$H_t = \frac{\Delta l_t}{\delta'_{22}} = \frac{\Delta l_t}{(1 + \mu) \int_s \frac{y^2 ds}{EI}} \Delta l_t = \alpha l \Delta t \quad (1)$$

Type:  $\Delta t$ ——The value of temperature changes, temperature difference between the maximum (or minimum) temperature and the closure, When temperature rises ,it's positive, otherwise negative.  
 $\alpha$ ——Linear expansion coefficient of material.

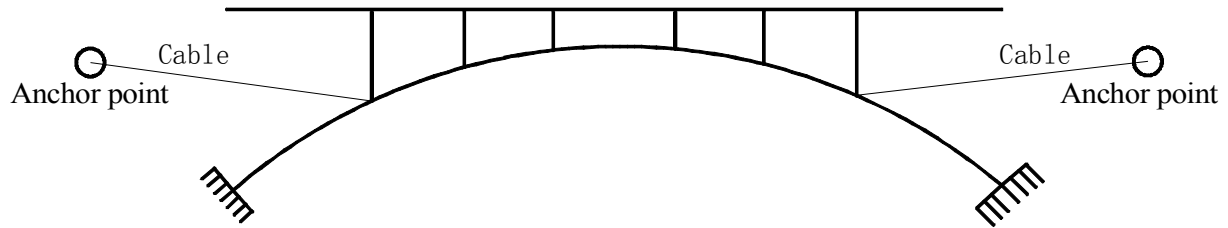


**Fig.8 Calculation sketch of internal forces in arch caused by temperature**

The additional internal forces in arbitrary cross section of arch caused by the temperature is:

$$\begin{cases} \text{bending moment : } M_i = -H_t y = -H_t (y_s - y_1) \\ \text{axial force : } N_i = H_t \cos \varphi \\ \text{shear force : } Q_i = \pm H_t \sin \varphi \end{cases}$$

If the cable diameter is  $d=0.1\text{m}$ , the length of the cable is determined according to the anchor point position, the elastic modulus is  $E=2.0 \times 10^{11}\text{pa}$ , and the linear expansion coefficient is taken as  $\zeta=1.2 \times 10^{-5}$ . Supposed the cable is installed  $10^\circ\text{C}$  above the closure temperature, at  $10^\circ\text{C}$  below the closure temperature stays temperature decreasing to  $20^\circ\text{C}$  in accordance with consideration(as shown in Fing.9).



**Fig.9 The situation of single cable**

Cable force in the stay cable:

$$F = EA\zeta = EA\zeta \Delta T$$

(2)

The cable force of the cable is  $376.8\text{kN}$  in the case of the decreasing temperature of  $10^\circ\text{C}$ . Normally, the cable is arranged in the upper and lower sides of the arch bridge, the cable force of the cable to the arch foot is  $2F=753.6\text{kN}$ . If the cable on the arch foot arm  $L$  is 3 meters, while the cable products positive moment on arch foot is:

$$M_{ls} = F \cdot l = 753.6 \times 3 = 2260.8\text{kNm}$$

(3)

## Conclusions

Although the effect of temperature has been considered in the design of bridges, the investigation of environmental temperature is not comprehensive, So it is particularly important to find a kind of self-adaptive control of environmental temperature. In this paper, a method for the internal force control of the statically indeterminate structure is presented, the results show that setting up the rigid cable at the appropriate temperature in reasonable position, can reduce the secondary internal force of the continuous girder bridge and arch bridge caused by the ambient temperature. The method present in this paper is only from the concept design of bridge, the concrete feasibility demonstration and engineering applications need to be further studied.

## References

- [1] YUAN Rui. Study on Disease Treatment and Reinforcement Technology of Reinforced Ribbed Arch Bridge[D] Chongqing jiaotong university:2010. (In Chinese)
- [2] ZHANG Qi-zhe. Analysis of Disease and strengthening Technology for RC Box Arch Bridge[J], Journal of Water Resources and Architectural Engineering,2009(03):94-95.(In Chinese)
- [3] Kehlbeck F. Einfluß der Sonnenstrahlung bei Brückenbauwerken[M] , Translated by LIU Xingfa, Beijing:China Railway Publishing House, 1981.
- [4] Yin Guansheng, Zhao Zhenyu, Xu Bing. Study on the thermal field of arch bridge by solar radiation action[J], Chinese Journal of Applied Mechanics,2014(06):939-945. (In Chinese)
- [5] FANG Zhen-zheng,HUANG Run, ZHENG Ze-qun. Temperature measuring and study of open spandrel rigid-framed arch bridge with box cross section[J], Journal of Fuzhou University(Natural Science),2005(02):212-217. (In Chinese)
- [6] JTG D60-2004.General Code for Design of Highway Bridges and Culverts[S].Beijing:China Communications Press,2004. (In Chinese)
- [7] XIANG Hai-fan,etc.Conceptual Design of Bridges[M].Beijing:China Communications Press,2011. (In Chinese)
- [8] MA Yang-qian. Research on Temperature Gradient and Automobile Load Effect of Continuous Box-girder Bridges[J], Guangdong Gonglu JiaoTong,2012(03):22-25. (In Chinese)