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Study on the response of temperature to the end displacement of suspension bridge

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Abstract. Relying on a single span suspension bridge, using the commercial finite software ANSYS, analyzes and studies the effect of temperature on displacement of suspension bridge beam end, and the temperature field of practical engineering is decomposed into the overall temperature gradient, temperature gradient of cable girder, tower and other temperature gradient temperature difference temperature mode. The finite element numerical calculation analysis is showed that: the overall temperature is taken the leading role of the displacement of the suspension bridge beam end, the temperature difference between beam and other components is with less obvious influence on the beam end displacement. while it is respectively lay the temperature sensor and displacement sensor in the beam and beam, it is feasible that the healthy monitoring in the long-term for beam temperature and displacement and establishing the correlation between temperature and beam end.

Keywords. Suspension bridge; temperature; beam end displacement; health monitoring.

1. Introduction

In recent years, the suspension bridge beam end attachment have become increasingly worse, such as expansion joints fatigue and serious damage, the studies have shown that compared with the cable-stayed bridge, the suspension bridge is particularly evident in the load-bearing bridge of the long-span cable structure. As the expansion device of Jiangyin Yangtze River bridge builted in 1999 in China due to serious damage and multiple repaired; Japan Dongming highway is opened to traffic 8 years, the average number of repairing joints is 1.6 times / sewing [1]. The telescopic devices, dampers and bearings of suspension bridge are expensive components The displacement parameter of the beam must be determined according to the displacement of the beam end. It is an urgent problem to research the reasonable prediction of displacement and angle value of the beam end. In terms of temperature factors, with the help of large bridge health monitoring system, respectively laying the displacement meter and thermometer in the main girder and girder end, according to the long-term monitoring data of displacement and temperature, the statistical relationship between the beam end and the effective temperature of the structure is analyzed statistically by many researchers. NI Y.Q. [2], Zhang Yufeng[3], Deng Yang[4]，Liu Yang [5] respectively healthy monitored the Hongkong Tsing Ma Bridge, the Jiangyin Yangtze River Highway Bridge, Runyang Bridge, Nanxi Yangtze River bridge, and built the mathematical model of longitudinal displacement and temperature of end beam bridge structure based on the measured data, and obtained the statistic law of beam end displacement under the action of some temperature. However, the finite element method provides another way to study the displacement temperature effect of the suspension bridge; therefore, a practical project in the suspension bridge as the basis, combined with the finite element method of temperature change under the effect of beam end displacement of the numerical solution to the ancillary facilities, the purpose of this paper is to provide a reference for the determination the beam end expansion joints and other ancillary facilities located in the parameters of the long - span suspension bridge.

2. Project overview

A suspension bridge is a large-span suspended suspension bridge in a trans-regional Grand Canyon, the layout is shown in Figure 1. The main cable span layout: 252m +1146m+126m, the full length 986m; the transverse direction of the bridge with 2% cross slope, deck width 24.5m, steel truss stiffened beam is 27m. The main cable, the sagging ratio of main cable F/L=1/9.6, center distance 27m, the plane cable layout; 69 pairs of sling used, sling standard spacing of 14.5m, the main span beam (truss at the center line) 7.5m.

3. Finite element model of the suspension bridge

The full - space rod model is established by the finite element software ANSYS, and the whole bridge is divided into 5409 elements and 1643 nodes. The finite element model is shown in Figure 2. In the model, the selected element type is shown in the table 1.

Table 1. Selected element type

component	Unit type	Remarks
Bridge tower	BEAM44	Space beam element
Steel truss stiffening girder	BEAM188	Space beam element
The main cable	LINK8	Space bar element
Sling and central cable	LINK8	Space bar element
Bridge deck and sightseeing channel	MASS21	Mass element

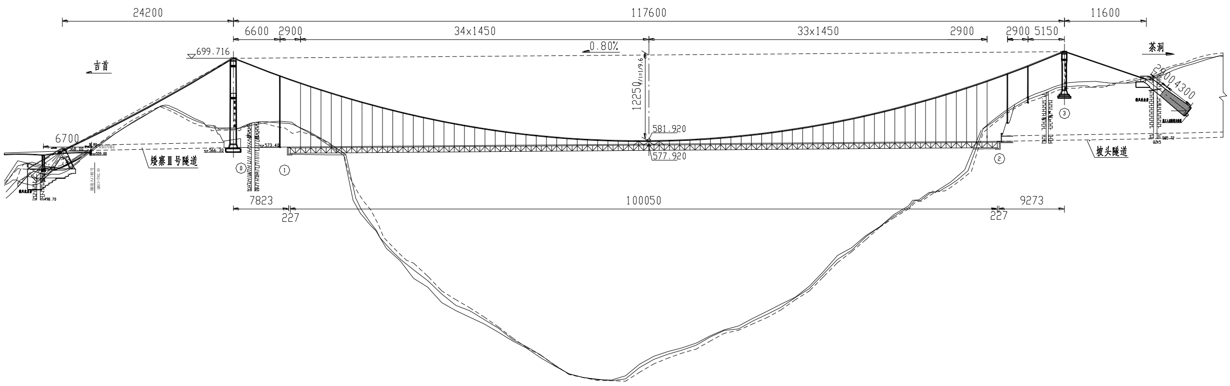

Figure 1. The suspension bridge layout (cm)

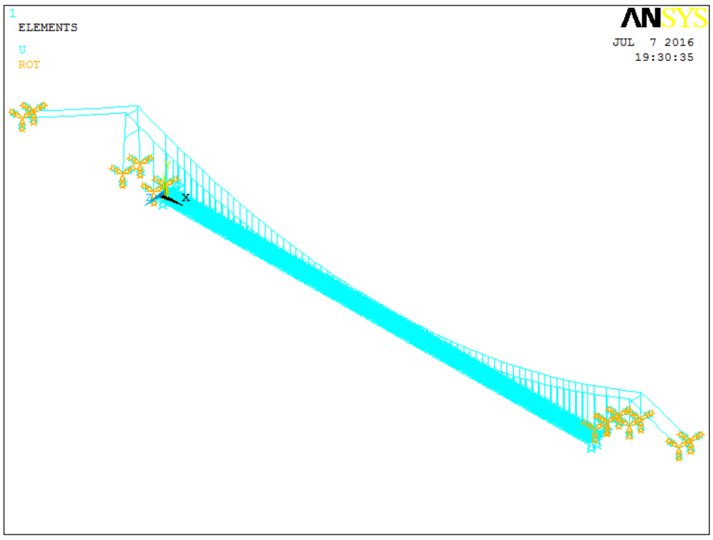

Figure 2. Finite Element Model of the Suspension Bridge

4. Temperature response analysis

Exposed to the continuous heat radiation and convection in the natural environment, the bridge structure will be affected by changes in temperature effect. In order to deeply research the effect mechanism of temperature on the suspension bridge beam end displacement, the temperature field applied to the bridge, is divided into system temperature (global temperature) and local temperature (gradient temperature), several modes of temperature difference are considered, such as the gradient temperature difference between the cable girder (GTDBTCG), gradient temperature of the main girder (GTOTMG) and gradient temperature of the bridge tower (GTOTBT).

4.1. Gradient temperature

The calculated the beam end displacement gradient of temperature effects are listed in table 2~ and table 4 by making use of the finite element model, from the above list of values, in the mode of temperature gradient system, it can be seen that the longitudinal displacement UX of the stiffening beam has little effect, the longitudinal displacement UX with only little effect in the millimeter level at 10℃temperature difference of the bridge tower (TDOTBT)and 15 ℃ temperature difference between cable and beam (TDBCAB); The beam end angle is less sensitive to various non-uniform temperature differences, and the vertical displacement of the beam ends is very small, without considered. In the effect, the displacement response curve with temperature were plotted in Figure 3 and Figure 4, the temperature gradient of the main beam is dominated by the gradient temperature difference, and the variation of the temperature difference shows nonlinearity.

Table 2. The beam end displacement caused by the gradient temperature along the tower

Temperature/℃		-10	-5	0	5	10
The longitudinal temperature gradient along the tower	UX/m	-1.66E-03	-8.29E-04	0	8.29E-04	1.66E-03
	RZ/rad	4.93E-05	2.47E-05	0	-2.47E-05	-4.94E-05
	RY/rad	-5.56E-09	-2.41E-09	0	2.41E-09	5.56E-09
The transverse gradient temperature along the tower	UX/m	1.58E-03	7.90E-04	0	-7.90E-04	-1.58E-03
	RZ/rad	6.75E-05	3.37E-05	0	-3.38E-05	-6.76E-05
	RY/rad	-1.08E-05	-5.41E-06	0	5.41E-06	1.08E-05

Table 3. The beam end displacement caused by the gradient temperature between the cable and the beam

Temperature /℃	-15	-10	-5	0	5	10	15
UX/m	-8.59E-03	-5.83E-03	-2.97E-03	0	3.02E-03	6.20E-03	9.48E-03
RZ/rad	-2.50E-03	-1.66E-03	-8.31E-04	0	8.30E-04	1.66E-03	2.48E-03
RY/rad	-9.28E-08	-7.81E-08	-4.11E-08	0	4.87E-08	1.11E-07	1.63E-07

Table 4. The beam end displacement caused by the gradient temperature along the main beam

Temperature /℃	-7.5	-5	-2.5	0	5	10	15
UX/m	3.12E-02	1.79E-02	8.93E-03	0	-1.79E-02	-3.57E-02	-6.25E-02
RZ/rad	5.27E-04	3.01E-04	1.50E-04	0	-3.01E-04	-6.01E-04	-1.05E-03
RY/rad	-5.56E-08	-5.56E-08	-1.85E-08	0	3.70E-08	5.56E-08	1.30E-07

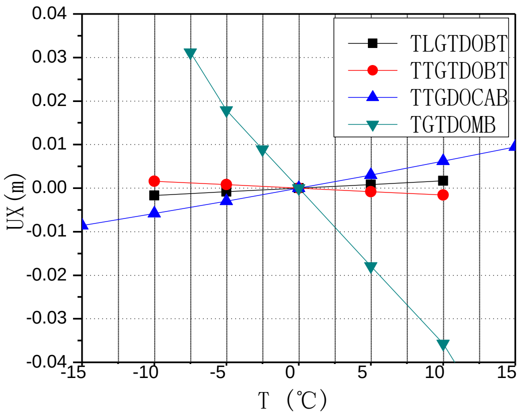

Figure 3. UX- Gradient temperature curve

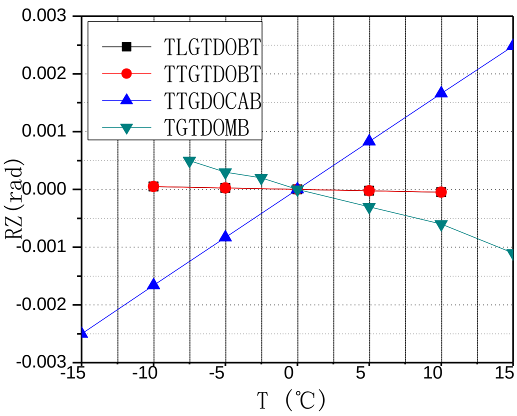

Figure 4. RZ- Gradient temperature curve

4.2. Overall temperature

The deformation of one-dimensional homogeneous rod under uniform temperature difference is related to the length, temperature difference and coefficient of thermal expansion of the material. The rod end displacement can be described as (1)

$$\triangle L=\alpha\times L\times\triangle T \quad (1)$$

In the formula: $\triangle L$ as the rod end displacement, α is named thermal expansion coefficient, L is the length of the bar, $\triangle T$ as the temperature difference.

Now the three methods can be used to obtain the system temperature difference of suspension bridge beam end displacement (longitudinal displacement UX), the first

The first is based on the finite element model of finite element and to consider the temperature change of the whole bridge system, the second method is the same as the former, the difference is only focused on the overall temperature of the main beam, the approximate main beam as a rod and formula to simplify the calculation of the longitudinal displacement of the beam. The girder length L 1000.5m, the telescopic zero point is at L / 2,the thermal expansion coefficient α of steel is 1.2E-5; the beam end displacement response results are listed in Table 5 by using the formula (1) and finite element model to calculate under the overall temperature. Table 5 is showed that the longitudinal displacements UX of the suspension bridge are very close to each other using the above three methods, in particular, the results of the two methods considering the whole temperature of the beam are the same within the error range, and the calculation results of the overall temperature of the bridge system are slightly smaller than the former, the deviation is only 3.8%.

For the angular displacement of the beam end, the overall temperature does not produce the beam end vertical displacement RY, only the beam end lateral displacement RZ produced, and the magnitude is relatively large. The longitudinal displacement UX of the beam end along with the overall change is plotted in Fig. 5, and the vertical displacement RZ is plotted in Fig. 6.

Fig.5 and Fig.6 are showed that the displacement of the beam varies linearly with the whole temperature. The geometric nonlinearity of the suspension bridge has little effect on the beam end displacement under the whole temperature. At the same time, Fig.6 we can see only considered the overall temperature and full bridge temperature compared to RZ displacement difference, the angular displacement RZ is with great difference, the temperature difference of the whole bridge should be taken into account when studying the angular displacement RZ.

Table 5. Beam end displacement caused by the overall temperature

T ℃	UX/m System temperature	UX/m Beam temperature	UX/m Theoretical method	RZ rad	T ℃	UX/m System temperature	UX/m Beam temperature	UX/m Theoretical method	RZ rad
-50	0.291	0.300	0.300	-0.008	5	-0.029	-0.030	-0.030	0.001
-45	0.261	0.270	0.270	-0.007	10	-0.057	-0.060	-0.060	0.002
-40	0.232	0.240	0.240	-0.006	15	-0.086	-0.090	-0.090	0.002
-35	0.202	0.210	0.210	-0.005	20	-0.114	-0.120	-0.120	0.003
-30	0.173	0.180	0.180	-0.004	25	-0.142	-0.150	-0.150	0.004
-25	0.144	0.150	0.150	-0.004	30	-0.170	-0.180	-0.180	0.005
-20	0.115	0.120	0.120	-0.003	35	-0.198	-0.210	-0.210	0.006
-15	0.086	0.090	0.090	-0.002	40	-0.226	-0.240	-0.240	0.006
-10	0.057	0.060	0.060	-0.002	45	-0.254	-0.270	-0.270	0.007
-5	0.029	0.030	0.030	-0.000	50	-0.282	-0.300	-0.300	0.008

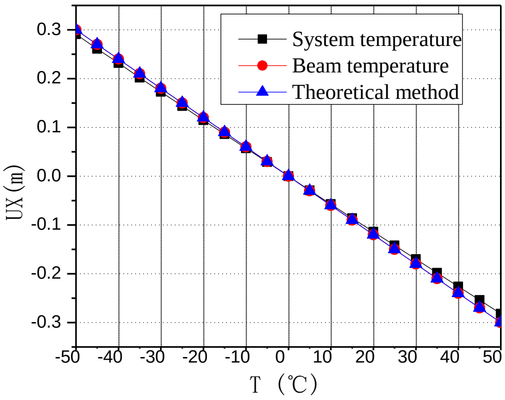

Figure 5. UX-System temperature curve

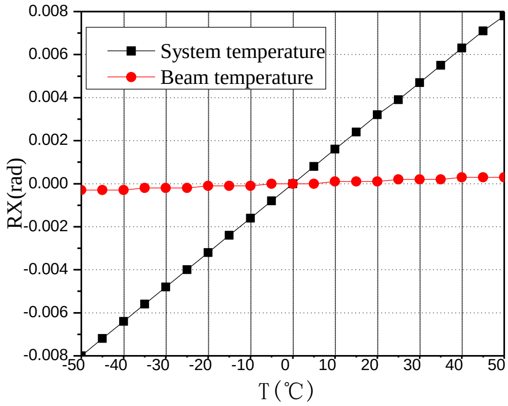

Figure 6. RZ--System temperature curve

5. Conclusion

In summary, the longitudinal displacement of end beam of suspension bridge is mainly related with the main temperature field, and the cable and tower temperature field is very small; the angular displacement of the beam end is effected in addition to the temperature field of the main beam itself, the impact of cable system temperature field cannot be ignored. Under the action of temperature, the performance of the system is such that the displacement performance of the beam is determined by the structural characteristics of the suspension bridge, which reflects the deformation of the stiffening beam itself and the restraint of the system. The suspension, floating suspension bridge system, the overall stiffening beam restraints are mainly from the bearing and sling system, while the slings only provide vertical restraints to the main beam, the lateral constraints is small. The bridge tower with the temperature field deformation led to the main cable and then transferred to the sling, and then the sling affect the main beam, but the effect is gradual weakening in the transmission process; the cable system temperature field is the most direct due to the expansion and contraction of the main beam caused by the longitudinal bending of the beam end corner RZ.

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