ce/papers Proceedings in civil engineering
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EXTENDED ABSTRACT
EUROSTRUCT

Analysis of the Thermal Effects on the Performance and Reliability of Post-Tensioned Integral Abutment Bridges

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Abstract

There are cases where the common approaches used to assess the temperature loading effects may not be sufficient, especially in the case of integral abutment bridges (IABs). In IABs, the incorrect choice of the design temperature may result in an unwanted tensional state in the bridge decks and additional loads on the abutments. For post-tensioned bridges, the combined effects of excessive temperature loads and loss of tension in the post-tensioned cables due to time-dependent phenomena like relaxation in steel and shrink-age and creep in concrete may lead to probabilities of exceedance of serviceability (or ultimate) limit states that exceed the code specifications and/or desired levels of safety, and to cascading negative effects on the operation of the road infrastructure. This research aims at assessing the sensitivity of IABs to the long-term effects of temperature loads and, in a second step, quantifying the probability of exceedance of relevant serviceability limit states.

Keywords

Thermal loads, Post-tensioned bridge, Shrinkage, Creep, Relaxation, Serviceability limit state

1 Introduction

Usually, maximum and minimum shade air temperatures recorded at weather stations over several years are included in technical standards in the form of isotherm maps and used to predict the design temperature a bridge may experience during its service life. However, there are cases where the standard approaches used to assess the temperature loading effects may not be sufficient, especially in the case of integral abutment bridges (IABs) [1] where the absence of free-moving decks requires an accurate choice of design temperature. Such a precise choice may be challenging in regions that experience frequent temperature changes [2] and, above all, exposure to extreme temperatures. Additionally, climate change may result in changes in average and extreme temperatures that a bridge may experience in future years. In IABs, the incorrect choice of the design temperature may result in an unwanted tensional state in the bridge decks and additional loads on the abutments. Moreover, the deck's cyclic expansion and contraction movement may result in strain ratcheting (i.e., a compaction effect on the backfill to the abutment walls).

For post-tensioned bridges, the combined effects of excessive temperature loads and loss of tension in the post-tensioned cables due to time-dependent phenomena, like relaxation in steel and shrinkage and creep in concrete, may lead to probabilities of exceedance of serviceability (or ultimate) limit states that exceed the code specifications and/or desired levels of safety, and to cascading negative effects on the operation of the road infrastructure. This research aims at assessing the sensitivity of IABs to the long-term effects of temperature loads and quantifying the probability of exceedance of relevant serviceability limit states.

For this purpose, the structural model of an existing post-tensioned IAB located in Shenzhen (Guangdong, China) has been developed and subjected to temperature loads based on temperature measurements on bridges in several Chinese provinces. Preliminary results show that a significant negative thermal stress leads to cracking and exceeds the considered serviceability limit states.

2 Modeling framework

The combined effects of thermal stresses and tension loss in post-tensioned cables due to slow phenomena are analyzed through a case study. For this purpose, an integral

https://doi.org/10.1002/cepa.2171

abutment bridge in Shenzhen (Guangdong, China) is selected. In addition to thermal loading and stress loss due to time-dependent phenomena, the bridge is subjected to the actions of vehicular traffic. Three different limit states are considered related to the maximum vertical displacement of the beams, the stresses in the lowest fiber of the cross-section, and the stresses in the post-tensioned cables.

2.1 Bridge model

A structural model is developed to represent an existing integral abutment bridge located in Shenzhen (Guangdong, China), the Maluanshan Bridge. This is a three-span post-tensioned bridge with a total length of 88 meters. Figure 1 shows a side view of the Maluanshan Bridge and a typical cross-section.

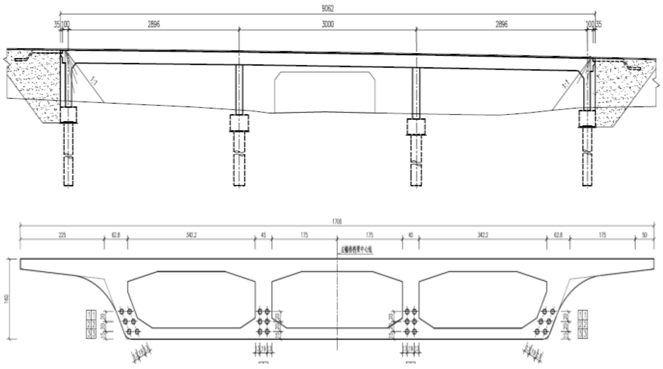

Figure 1 Front view and cross-section of the Maluanshan integral abutment bridge in Shenzhen.

For this research, because of the choice of the limit states of interest, assuming a linear behavior of the bridge deck under operating loads is reasonable. Consequently, the bridge's structural components are modeled with equivalent linear elements, one for each row of piers and six for each beam. Each span is subdivided into six elements to account for variations in the section and position of the post-tensioned cables. The elements used to model the beams are homogeneous, considering the presence of both regular and post-tensioned steel. The interaction with the ground is modeled with springs with equivalent stiffness.

For post-tensioned cables, the long-term losses due to concrete shrinkage, concrete creep, and steel relaxation are modeled according to the provision given in Eurocode 2 [3]. The elastic problem has been solved with the classic displacement-based method.

2.2 Thermal and traffic loads

The thermal loads are described by uniform and linear temperature gradients (ΔT_u and ΔT_l) assigned to each element of the girder. These values are assumed equal for all the bridge components. The reference temperature value is assumed to be T_{ref} = 20° C. The values of the assigned temperature gradients are based on temperature measurements referred to bridges in the Guangdong (1-time series), Fujian (4-time series), and Hebei (5-time series) provinces in China.

The measurements correspond to winter and summer, expressing the extreme values in terms of temperature variation, and account for both daily and hourly variations. Table 1 summarizes the available data.

Table 1 Thermal gradients from the recorded time-series

Time-Series	Initial time	Final time	Time step [h]	Max ΔT_u [°C]	Min ΔT_u [°C]	Mean ΔT_u [°C]	Max ΔT_l [°C]	Min ΔT_l [°C]	Mean ΔT_l [°C]
Shenzen (Guandong)	07-29-2018	08-01-2018	0.5	13.8	11.8	12.8	-0.8	-1.8	-1.4
Zhangzhou (Fujian) T1	01-28-2015	02-02-2015	0.5	-2.0	-5.2	-3.7	1.8	-1.4	0.2
Zhangzhou (Fujian) T2	08-02-2015	08-06-2015	0.5	17.5	11.8	15.3	3.9	-1.1	1.9
Zhangzhou (Fujian) T3	01-23-2016	01-27-2006	0.5	-3.3	-9.3	-7.3	0.3	-2.7	-1.5
Zhangzhou (Fujian) T4	07-21-2016	07-22-2016	0.5	19.9	12.7	16.2	4.0	-2.3	0.7
Hannan (Hebei) T1	07-22-2014	07-31-2014	0.5	13.9	5.4	9.2	2.8	-3.2	-0.8
Hannan (Hebei) T2	08-01-2014	08-04-2014	0.5	15.1	8.75	11.9	-0.5	-2.9	-1.6
Hannan (Hebei) T3	08-06-2014	08-08-2014	0.5	7.9	2.2	5.4	1.1	-1.7	-0.2
Hannan (Hebei) T4	01-20-2015	01-23-2015	0.5	-14.6	-18.8	-16.3	1.6	-1.4	0.0
Hannan (Hebei) T5	07-14-2015	07-18-2015	0.5	14.7	3.8	6.9	1.1	-1.4	0.0

A model that considers the values of such gradients as functions of the site's environmental conditions, particularly as functions of season, 10 min wind speed, diffuse solar radiation, and direct solar radiation is currently been developed.

The traffic load is modeled according to the Chinese standard [4] for four-lane bridges, resulting in a transverse deck dimension of 17 m, as in the bridge chosen for the case study. According to this standard, the traffic load derives from overlapping a uniform load and a concentrated load, as in Figure 2. The uniform load per lane is distributed over the entire length of the bridge with the same sign, while the position of the concentrated load varies in discrete steps of 0.1 m. This step is the same step used to check for stresses and strains in the beam cross-sections.

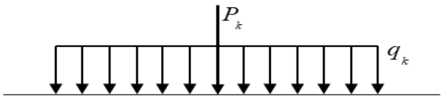

Figure 2 Scheme of the traffic load

3 Preliminary results

An initial analysis intended to assess the sensitivity of the performance of the post-tensioned integral abutment bridge used as a case study on the value of the temperature gradients can be performed considering the mean values shown in Table 1.

Figures 3 and 4, which is a zoom of Figure 3 in the range where the larger displacements occur, show the results in terms of displacements obtained for the four cases deemed the most unfavorable (Fujian T2, Fujian T4, Hannan T2, and Hannan T4). The value of the maximum displacements in all four cases is significantly lower than the threshold value imposed for the serviceability limit state by the Chinese standards [11], which is v_{sl} =0.048m. The values of the displacements are quite low when considering a large value of the uniform gradient of temperature. Still, the concrete stresses at the bottom fiber of the cross-section σ_{ci} reach the tensile strength f_r (as shown in Figure 5) with possible crack formations.

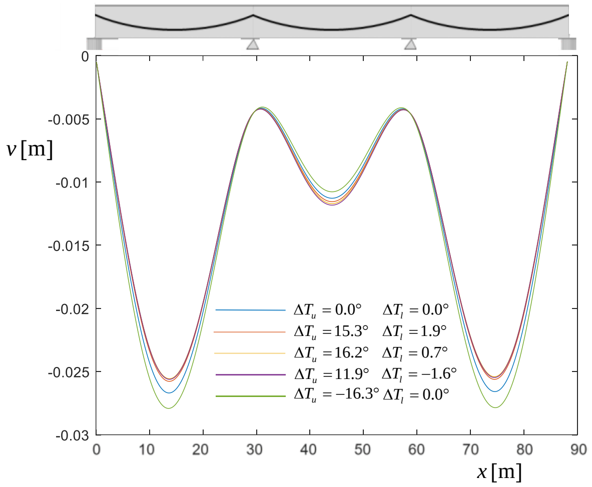

Figure 3 Bridge displacements for several combinations of the uniform and linear temperature gradients

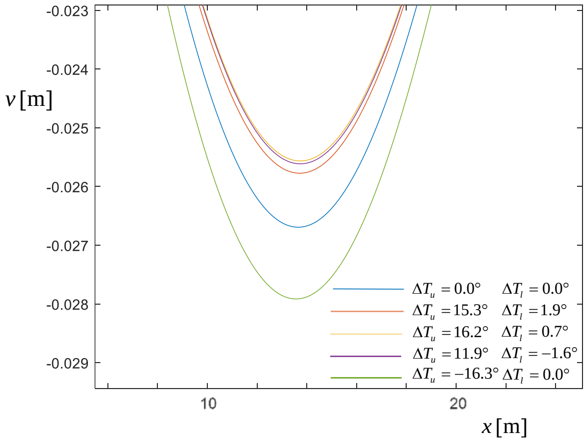

Figure 4 Detail of Figure 3 in the range of the maximum displacements.

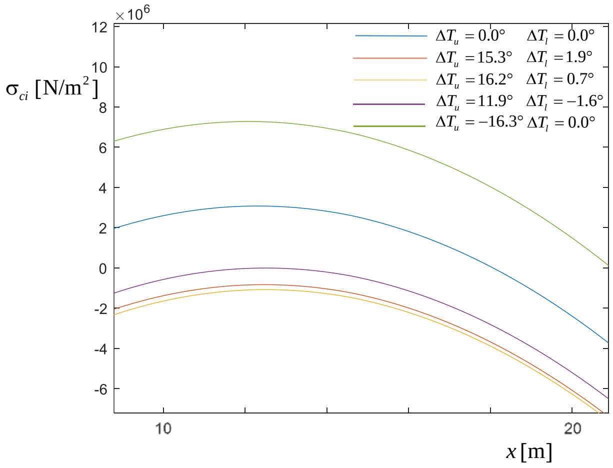

Figure 5 Concrete stresses at the bottom fiber of the cross-section

To consider the effects of the cracks, the model considers an effective moment of inertia I_e along the span of each element of the beam where $\sigma_{ci} > f_r$ according to the method proposed by Branson [5].

When the cracked sections are considered, as for the results in Figure 6, the displacements increase and, for the worst combination of thermal gradients, i.e., ΔT_u = 16.3° and ΔT_l = 0.0°, the maximum displacement is larger than v_{sl} (i.e., v =0.05m).

Figure 6 shows the combined effects of the thermal gradients and loss of tension in the post-tensioned cables assuming a period of 100 years for the time-dependent phenomena. Lastly, it should be noted that there is a significant difference between the effects of time-dependent phenomena for cracked and uncracked girders, as it is possible to see comparing the displacements in Figure 6 and those in Figure 7 where the latter shows the combined effects of the thermal gradients and loss of tension in the post-tensioned cables for a girder without cracks.

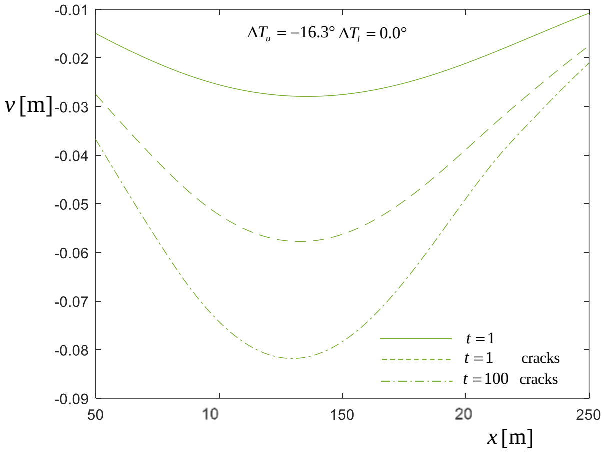

Figure 6 Comparisons between displacements at 1 and 100 years, with and without considering cracks.

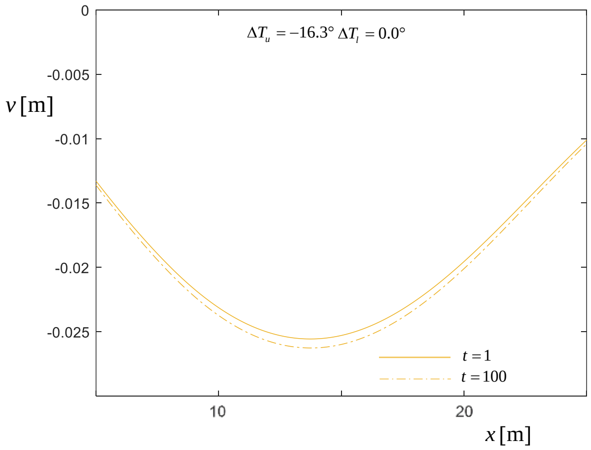

Figure 7 Comparisons between displacements at 1 and 100 years for a case without cracks

4 Conclusions

The preliminary results presented show that there are cases, mostly related to extremely low temperatures, where the combination of thermal gradients and long-term phenomena may lead to the exceedance of serviceability limit states with detrimental consequences on the operation of post-tensioned integral abutment bridges. Therefore, there is a need for a more detailed analysis to estimate the probability of loss of functionality of the bridges in the long term and predict the consequent impact on road infrastructure.

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