Field Examination and Fatigue Analysis on Longitudinal Steel Diaphragms in Box-girder of Cable-stayed Bridges

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Summary

Steel box-girders have been widely used in modern long-span bridges due to their aesthetic shape, large torsion stiffness and desirable aerodynamic properties. In long-span cable-stayed bridges, to maintain desirable performance of steel decks and pavements, longitudinal diaphragms are frequently adopted. However, field examination on the diaphragms in a cable-stayed bridge in China shows that significant damage could be observed at the joint of chords and gusset plates after only several years the bridge was open to traffic. This paper presents the typical pattern, location and the crack lengths obtained through the non-destructive testing methods. An advanced fatigue analysis approach is proposed, which consists of a comprehensive vehicle load model obtained from a toll station and a multi-scale finite element model of the bridge. According to the analysis results, the diaphragms play an important role in the stress distribution of the decks. In addition, it is observed that the predicted fatigue lives of specific details are very short, which is in agreement with field observation. The findings of this paper provide references to the fatigue design and retrofit strategies of bridges with such details.

Keywords: field examination; fatigue analysis; longitudinal steel truss; steel box-girder; cable-stayed bridge; finite element.

1. Introduction

For long-span cable-stayed bridges, longitudinal diaphragms are frequently adopted in the girders, so as to increase the stiffness of girders and mitigate the fatigue damage of steel decks and pavements. In China alone, a number of steel cable-stayed bridges have been built in recent years with longitudinal diaphragms inside the box-girders. However, significant damage has been frequently observed at the joint of braces and gusset plates, as shown in Fig.1, which may occur after only several years the bridges are open to traffic, resulting considerable repair costs and influence on the bridge performance.

(a) *Minor to medium crack (RCB)* (b) *Through crack (RCB)*

Fig. 1: Field observed cracks in longitudinal diaphragms

2. Field examination

In order to monitor the cracking of steel box-girders of the RCB, field inspection was conducted every year from 2007 to 2013. It is found that most cracks are at the diagonal braces where the pipes intersect with the gusset plates, and the cracks mainly develop in the circular direction of the pipes. Fig.2 shows the total crack lengths detected from 2007 to 2013, where the crack propagation is faster before 2009, and become slower thereafter. According to the statistical results on total crack length by the end of 2007, as shown in Fig.3, locations 2 and 6 have the largest cracks among the eight locations, followed by locations 3 and 7; while the cracking of locations 1, 4, 5 and 8 are less severe.

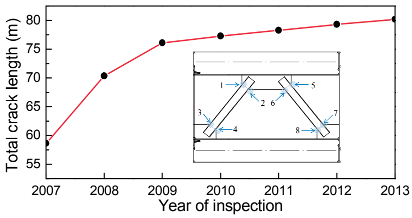

Fig.2: Total crack lengths in different years

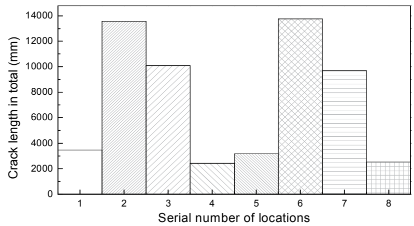

Fig.3: Total crack lengths at various locations

Fig.3: Profile of time-dependent total crack lengths

3 Probabilistic finite element analysis

In order to investigate the influence of longitudinal diaphragms on the bridge, a multi-scale FE model of the RCB is developed. According to the FE analysis with and without diaphragms, the existence of longitudinal diaphragms makes the stress distribution more uniform and smaller stress amplitudes may mitigate the damage in steel decks and pavements.

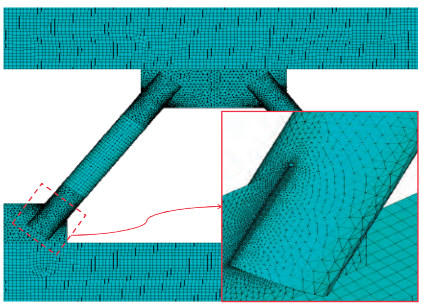

Fig. 4: Sub-model of diaphragm

To further look into the failure mechanism of the diaphragms, a sub-model of one chamber of girder at the mid-span is built with refined element mesh, as shown in Fig.4, based on which fatigue analyses are conducted, combined with a comprehensive vehicle load model obtained from a toll station. According to the analysis results, as shown in Table 1, the mean lives of the brace-gusset-plate joints of the longitudinal diaphragms at mid-span are unexpectedly short, being only about six to eleven years, and the lives might be even shorter considering the high uncertainties in the analyses and different locations along the bridge. Therefore, improved design of the steel diaphragms is required, so as to increase their fatigue life; for existing diaphragms, proper repair actions should be taken to ensure the desired performance of the steel girders.

Table 1: Predicted fatigue lives of various locations

Serial number of locations	S_{re} (MPa)		N_c		*T (year)*	
	$\mu_{\ln Sre}$	$\sigma_{\ln Sre}$	$\mu_{\ln Nc}$	$\sigma_{\ln Nc}$	μ	σ
1	10.376	0.405	4.225	0.466	10.658	6.462
2	12.428	0.942	4.326	0.478	6.359	4.031
3	12.178	0.993	4.243	0.532	6.930	4.507
4	10.296	0.618	4.221	0.423	11.230	7.165
5	10.376	0.577	4.016	0.435	10.818	6.666
6	12.407	0.982	4.121	0.413	6.425	4.254
7	12.074	0.955	4.204	0.455	6.901	4.397
8	10.236	0.604	4.243	0.532	11.271	7.010