Advanced Engineering Forum *Online: 2012-07-26*
ISSN: 2234-991X, Vol. 5, pp 189-194
doi:10.4028/www.scientific.net/AEF.5.189

Study on Suspender's Fatigue Performance of Half-through CFST Arch Bridge Due to Vehicular Loads

Hang Sun[1, a], Jun Ma[1,b], Bo Yu[2]

[1]School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin, China, 150090

[2]Research Institute of Highway Ministry of Transport, Beijing, China, 100082

[a] bridge_hit@163.com, [b] mjlxd@163.com

Keywords: CFST arch bridge; deck type; fatigue performance of suspender; The frequency value chart of vehicle load

Abstract: Due to the repeated action of vehicular loads, fatigue failure of suspenders of half-through arch bridge is main failure type. Usually the stress history of suspender is relevant with the vehicle load, dynamic property of structure and so on. In this paper, the traffic load spectrum investigation of Ha-Tong road is constructed through a 24-hour traffic flow investigation; And the space FEM established to get the stress response；Assume the fatigue performance of suspender as stochastic variable, the stress history of suspender is a stochastic process which changes with time, fatigue reliability analysis model is suggested based on accumulated damage model；Taking YIlan bridge as an example, the study on the effect of suspenders' length and deck type are carried out. The research method and results can be referenced while designing or evaluating the same bridge type。

1. Introduction

Concrete filled steel tube arch (CFST) bridge is a kind of popular bridge in mainland of China, and most of them are half –through CFST bridges. The parallel single suspender is usually applied in this kind of bridges. However, the investigation shows that the half-through suspender may be dangerous owing to its structural system. A common example is the Jinshanjiang Bridge in Yibin, China. The shortest pair of suspenders of north side of this bridge were damaged, and then another three pairs of suspenders were cracked after couples of minutes. Finally, almost of the whole bridge fell into the river[1 2]. Another example goes to Shouchun Road Bridge in China. 28 suspenders had to be replaced since the shortage of protection after working about 10 years[3].

Combining the designing work of Liuwu bridge in Lhasa, Chen Bing studied the fatigue performance of suspender[4], and found that fatigue damage is the main reason for the suspenders' failure. And the analysis of a half-through arch bridge carried by Gu An-bang[5] showed that the dynamic load impact effect on shorter suspenders is much larger than that on longer suspenders.

The study on suspenders' performance has received more attention, but not reaching explicit conclusions. above reasons has hindered the development of half-through CFST arch bridge.

2. Fatigue Cumulative Damage Rule

The fatigue failure of structure is an accumulation process of structure interior damage, with the increase of cycle number, the fatigue damage increases monotonously, hence the structure resistance declines. If define the accumulative damage as D(n), then the limit state equation is[6]:

$$D(n) - D_c \leq 0 \tag{1}$$

where D(n) is the cumulative damage,which is a stochastic process and increase monotonously with the cycle number n； Dc is the critical damage value and also a stochastic process。When formula holds,the members are safe.

Usually fatigue damage D(n) is defined in Miner rule, because Miner rule can predict the mean life of structure due to stochastic loading more easier, which can be expressed as following equation:

$$D(n) = \sum_{i=1}^{n} \Delta D_i = \sum_{i=1}^{n} \frac{1}{N_i} \tag{2}$$

Where N_i is the corresponding fatigue life of stress amplitude, considering the S—N curve equation, then:

$$D(n) = \sum_{i=1}^{n} \frac{\Delta\sigma_i^m}{C} = \frac{nE(\Delta\sigma^m)}{C} \tag{3}$$

Then the limit fatigue state equationcan be obtained:

$$\frac{nE(\Delta\sigma^m)}{C} - D_c = 0 \tag{4}$$

Where C , $\Delta\sigma$ and D_c are stochastic variables。Material parameter C obeys lognormal distribution, the mean value of logarithm and const logarithmic standard deviation can be obtained from fatigue testing with constant amplitude. And as a critical damage value, D_c is a stochastic variable in general case, which obeys lognormal distribution, and the mean value is 1.0, the standard deviation is 0.3.

3. The Fatigue Reliability Analysis of Suspenders

3.1 The Space Finite Element Model

Yilan Mudanjiang Bridge is located on the west of old city zone of Yilan country, the main arch rib includes two separation types which is composed of triangle steel tube truss, and the transverse braces were cancelled in design. The arch axis of main arch is catenary, the arch-axis coefficient m=1.756, the net span L0=100m, the net vector height f_0=25m,the net rise-span ratio is 1/4. The spacing of suspenders is 6m, the bridge deck is 6m T beam.

The finite element calculation in this paper is finished by ANSYS. The main arch rib is modeled by linear space beam unit of three nodes. The suspenders are the connecting components between arch rib and suspension member transversal girder, using the tensioned-only bar elements, of which the influence of initial strain should be considered. The suspension member transversal girder, the column of cross beam and wind bracing can all be simplified into general beam structure, which can be modeled by linear space beam unit of two nodes. The floor system can be modeled by shell element of four nodes, the style of which has a great influence on the lining structure static behavior and fatigue. The FEM is shown in figure 2. The force properties of the suspenders are compared between the longitudinal beam of continuous girder and of simply supported-continuous. In order to distinguish, the longitudinal beam of continuous girder is called the floor system of A style, and the simply supported-continuous is called B style.

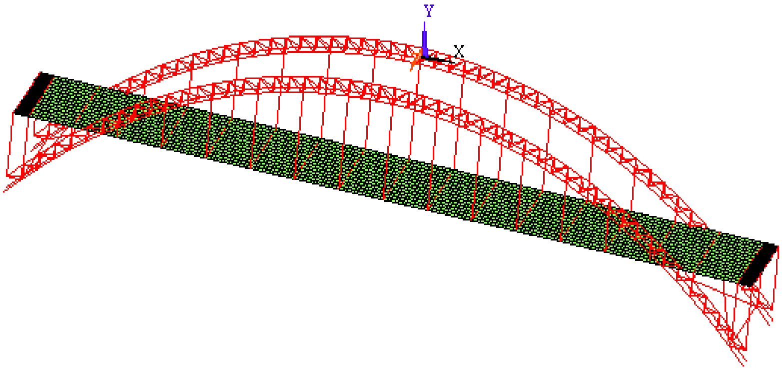

Fig. 2 The space finite element model of Yilan bridge

3.3 Stress History of Suspenders

In fact, the stress amplitudes are variable to different suspenders, under the same live load M1. The stress amplitude is reduced from 1# to 7#. Because of the longitudinal rigidity of the floor system, the force of the structure that M1 acts on should be distributed by the relative stiffness. The distribution of the force is related to the longitudinal rigidity of the floor system, the longitudinal rigidity of the suspenders and the in-plane stiffness of arch rib. Therefore, the shorter suspender is distributed to a larger axial force, and so as the stress amplitudes. So comparing to other suspenders, the shorter one is under the dangerous state and the fatigue reliability is lower. Under loads effect at all levels, the maximum amplitude of the suspenders' stresses are shown in figure 3.

Fig.3 The stress amplitude of suspenders to all levels loading

From figure 3, we can find that the stress amplitude of $1^{\#}$ is much larger than that of other suspenders, and the increase amplitude decay rapidly from $1^{\#}$ to $3^{\#}$. In general, the difference of stress amplitude is obvious between $1^{\#}$ and $2^{\#}$,That is , the short suspender effect is restricted to the shortest two suspenders, and other short suspenders do not exist this problem.

3.4 Stress History of Suspenders to different deck type

From the point of fatigue reliability, analysis was carried out aiming to different deck types, the result is shown in figure 4.

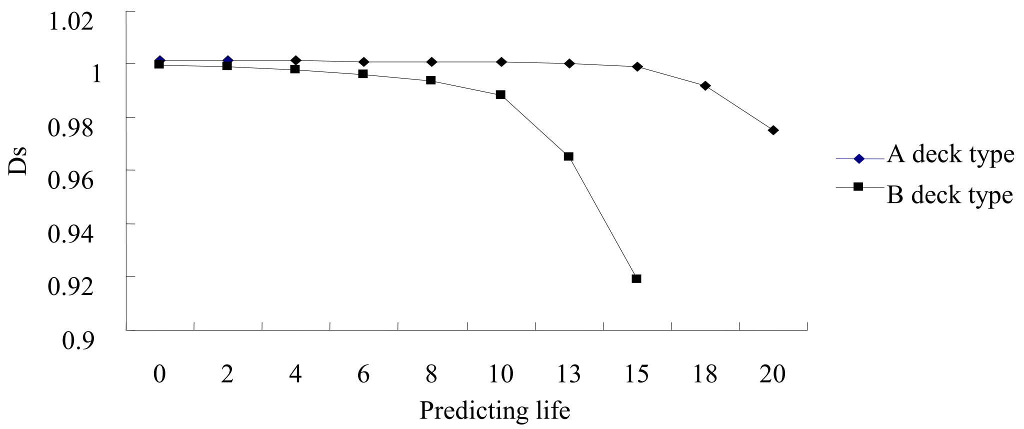

Fig. 4 Comparison of predictive DS value

It can be seen from figure 4, the remaining fatigue performance index of suspenders of A deck type is smaller than that of B deck type. Also with the the increase of service life, the difference increases.

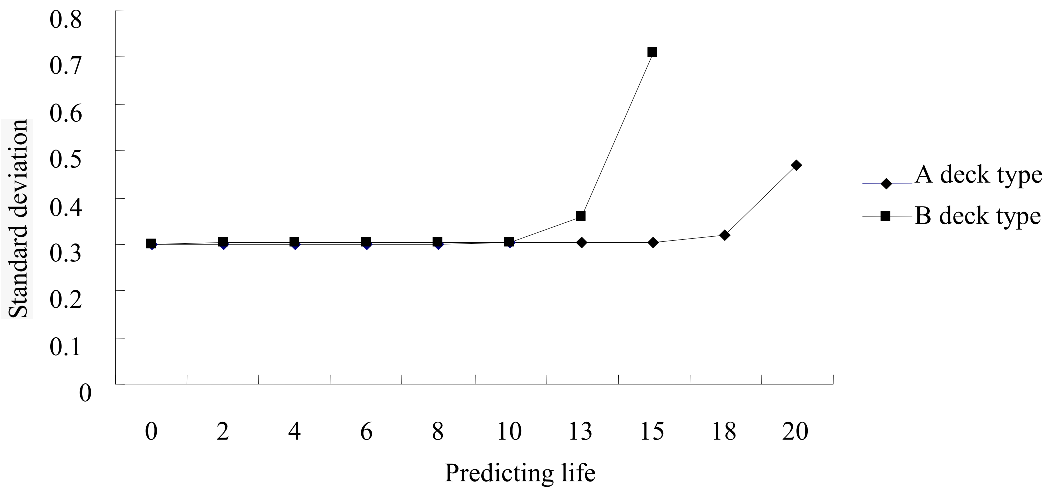

Fig. 5 Comparison of predictive value of DS standard deviation

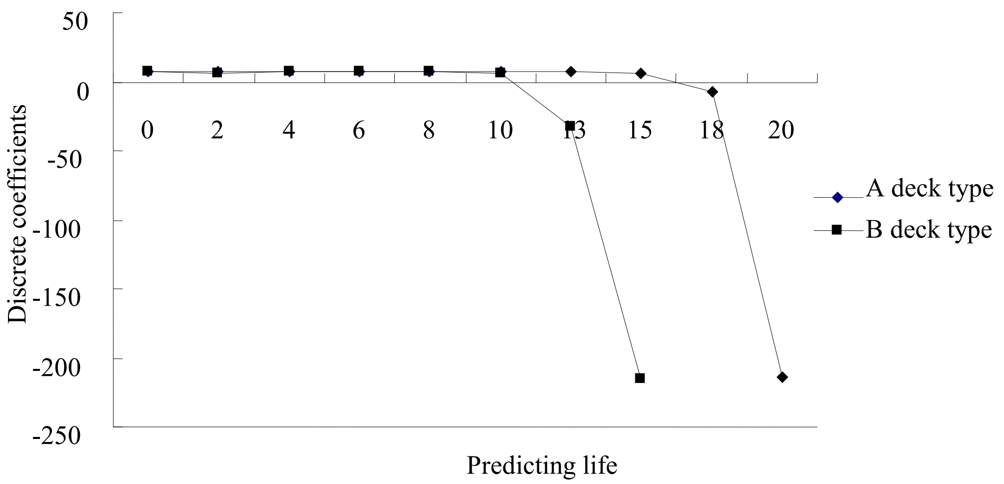

Fig. 6 Comparison of predictive value of DS discrete coefficients

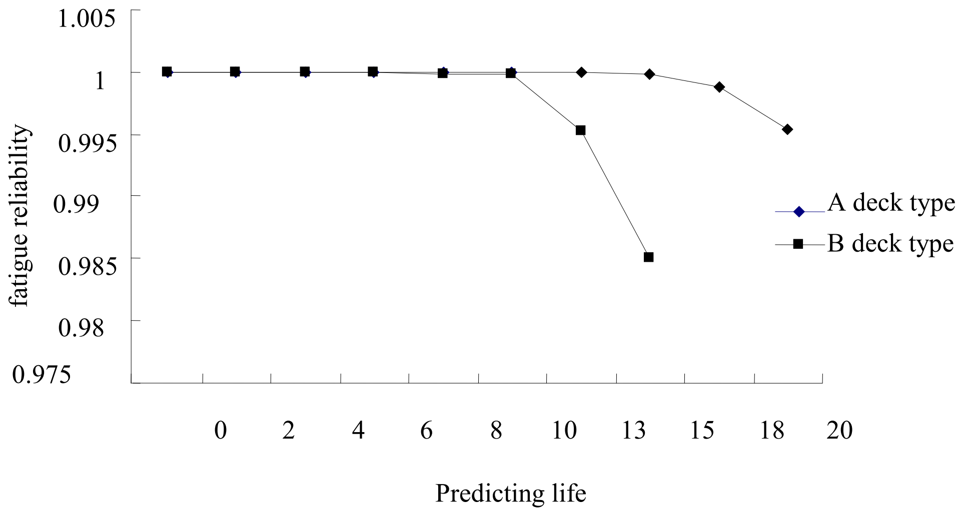

Fig. 7 Comparison of predictive fatigue reliability of suspenders to different deck types

From figure 5to6, we can find that the standard deviation of the retention fatigue index value DS of the prediction of A style's suspenders is more than that of B style, under the same service life and same application conditions. With the increasing of the service years, this difference is increased gradually. The standard deviation of the predict retention fatigue index value DS of A style's suspenders in the 22th year is basically the same as that of B style at the 27th year. And from figure 7, we can find that the fatigue reliability of the suspenders of A style is less than that of B, under the same service life and same application conditions. With the increasing of service lives, this difference is increased gradually. The fatigue reliability of the suspenders of A style in the 22^{th} year is less than that of B style at the 27^{th} year. Therefore, the floor system of B style should be preferred to use for the half -through type or through arch bridges (longitudinal beams are simply supported-continuous), from the point of fatigue reliability.

5 Conclusions

The simplified load frequency spectrum of Ha-Tong Road is provided by traffic volume investigation, based on the principle of equivalent fatigue damage. In this paper, the load of the suspender is taken as stochastic process, and the fatigue strength of the suspender is considered as random variable, thus, the analysis model of dynamic fatigue reliability based on the cumulative damage model is given. Also, this article establishes a finite element model of an arch model, studies the short suspender effect, and concludes that the short suspender effect is restricted to the shortest two suspenders comparable to the different influence of fatigue reliability of different floor system forms. At the same time, the deck system of simply supported-continuous longitudinal beams can reduce the stress amplitude of all suspenders' live load, and then improve the fatigue reliability of the suspenders. In short, this deck type is suggested under the consideration of suspenders' fatigue reliability.

References

[1] JGJ 94-2008, Building pile foundation technical specifications, Beijing, 2008. (in Chinese)
[2] Baochun, Chen. Concrete Filled Steel Tube Arch Bridges. People's Communications Publishing House, 1999:50~58[In Chinese]
[3] Baochun, Chen. Concrete Filled Steel Tube Arch Bridges Engineering Examples. People's Communications Publishing House, 2002:11~28[In Chinese]
[4] Code for Design of Highway Bridges and Culverts(JTG D60-2004), People's Communications Publishing House, 2004. [In Chinese]
[5] Ruqing Zhang, Xuegang Yin and Ming Dong, computational structural dynamics. Chongqing University Publishing House, 1987:41~109. [In Chinese]