Durability Evaluation and Rational Durability Analysis of Cables for Bridges in China

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Abstract. The cable bridges have developed in leaps and bounds in China. With the increase of service time, the diseases affecting the durability and safety of structures have also been exposed, and cables for some bridges have to be replaced in advance. Based on the investigation of the bridges which have replaced cables in our country, this paper analyses the durability of the cables for bridges and the rational durability of the common cables system in our country, so as to provide reference for the selection, application and maintenance management of the cables for bridges.

1 Introduction

Cables for bridges (including stay-cables of cable-stayed bridges, suspenders of half-through and through arch bridges, etc.) are the main bearing components of cable bridges. They are generally arranged outside the girder and are in a high-stress state. The cables are sensitive to external damage. With the increase of served time, rust, wire breakage and other damage are gradually exposed in actual operation. Many bridges have to replace suspenders in advance. In serious cases, cable breakage occurs, causing bridge collapse accidents and resulting in bad economic losses and social impact.

Supported by the Scientific and Technological Project of Zhejiang Highway Administration, the research team has carried out the investigation of 74 cable bridges in China, including 34 cable-stayed bridges (Table 1) and 40 suspension arch bridges (Table 2). On the basis of investigating the structure form, damage characteristics and replacement time of the cables of bridges, the paper summarizes the damage characteristics and average service life of the cables of bridges in use in China, and analyses the durability of the cables and the rational durability of the common cables system, so as to provide a reference for the selection, application and maintenance management of the cables in the future.

Table 1. 34 cable-stayed bridges surveyed

Province	Sichuan	Guangdong	Guangxi	Zhejiang	Hubei
Bridge name	Shimen Bridge of the Jialing River, Sanda Nujiang Bridge、Qianwei Minjiang River Bridge、Jiao ping bridge of jinsha river、Three fuljiang bridge、Chongqing Lijiatun Yangtze River Bridge、Chongqing Wan'an Bridge、Tongling Yangtze River Bridge、Fuling Yangtze river bridge in chongqing	Guangzhou Haiyin Bridge、Nanhai Jiujiang Bridge、Dongguan Nange Bridge、Foshan Xiqiao Bridge、Zhuhai Qi'ao Bridge、Nange Bridge in Dongguan City	Hongshuihe Railway Bridge、Liuzhou Huxi Bridge、Nanning Baisha Bridge、Zhangzhou Yunlong Bridge	Jinhua Jinyu Bridge、Shangyu Zhangzhen Bridge、Shangyu People's Bridge	Wuhan Baishazhou Yangtze River Bridge、Han County Hanjiang Bridge
Province	Yunnan	Jiangxi	Shanghai	Shandong	Tianjin
Bridge name	Baoshan Sanda Nujiang Bridge	Nanchang Bayi Bridge	Hengfeng Road Overpass、New five bridge	Jinan Yellow River Highway Bridge	Yonghe Bridge
Province	Shanxi	Hunan	Jilin	Henan	
Bridge name	Sanyuan Xinlong Bridge	Changsha Yinpenling Bridge	Linjiangmen Bridge	Lushan Bridge、Lushan Bridge	

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Table 2. 40 suspension arch bridges surveyed

Province	Sichuan	Guangdong	Guangxi	Zhejiang	Hubei
Bridge name	Yibin small south gate jinsha river bridge、Dadu river bridge in ebian county、Leshan city, shawan dadu river bridge、Panzhihua naked fruit jinsha river bridge、Chengdu qinglongchang overpass、Tianjin bridge, mianyang city、Fujian bridge, mianyang、Xinlong aoqiao, neijiang, chengdu-chongqing expressway、Deyang changjiang road bridge	Dongguan hongfu bridge、No. 2 bridge of liuxihe reservoir in conghua、7/5000 Nanhai sanshanxi bridge、Ya ji sha bridge、Fochen bridge, foshan	Sanan yongjiang bridge、Yongjiang bridge、Wenhui bridge, liuzhou、Nanning pu miao bridge	Wuyi hot spring bridge、Hangzhou yeqingdou bridge、Jinhua shuanglong bridge、Taizhou ji li Chen bridge、Welcome interchange in taizhou、Shaoxing fuen bridge、Shaoxing jianhu bridge	Wuhan circum-city expressway K94+718 separated intersections
Province	Hainan	Liaoning	Anhui	Shandong	Xinjiang
Bridge name	Qiongzhou bridge	Shenyang changqing bridge	Hefei shouchun road bridge	Jining beijing-hangzhou canal bridge	Kongquehe bridge
Province	Fujian	Henan	Shanxi	Shanxi	
Bridge name	Wuyishan mansion bridge、Nanping yuping bridge、Fuzhou jiefang bridge、Quanyi bridge of fu 'an city、Longyan river south bridge	Shahe rainbow bridge, taishan road, luohe	Taiyuan YiFen bridge	Bridge of shu river and han river、Hanzhong panjiahe bridge	

2 Durability evaluation of cables for bridges in China

According to the data analysis of 74 bridges that have replaced cables, the cables of Shawan Dadu River Bridge in Leshan City have the shortest service life for four years, and the longest one is the cables of Fujiang Bridge in Santai, Sichuan Province for 22 years. The average service life of cable is 12.5 years, and the service life of cables is concentrated in 4-15 years. 57 of the 74 bridges surveyed are within this range, accounting for 77.0% of the total number of bridges which have replaced cables.

The factors causing cable replacement in advance include protection damage, water ingress, steel wire rust, wire breakage, wire slippage, anchorage rust, cracking, fire and sudden impact. The main factors are cable body protection damage and steel cable rust. 69 of 74 bridges have replaced cables due to PE damage and steel wire rust, accounting for 93.2% of the surveyed bridges.

The development of cable protection system in China can be roughly divided into three stages: wrapping protection with glass wool cloth, grouting protection with cement slurry (or butter) in casing and hot extrusion PE protection. In 1988, hot extrusion PE protection was successfully applied to Jiujiang Bridge in Guangdong Province. After that, this new cable protection system was adopted by almost all of the cables for bridges.

The region of bridges which have replaced cables is mainly concentrated in Sichuan, Yunnan, Guangdong, Guangxi and Zhejiang, totaling 48 bridges, accounting for 65% of the total number of bridges surveyed. The main reason is that the climate in these areas is hot and humid,

and there are many corrosive Cl-ions in the air of coastal areas, which leads to serious rust of cables.

3 Rational durability analysis of common cable system

The cable system includes three parts: cable, anchorage system and protection system. The survey data show that the common cable system in China includes PE protection parallel steel heading anchor cable, PE protection parallel steel cold (hot) cast heading anchor cable, high strength steel strand clip group anchor cable, PE protection strand extrusion anchor cable, etc. The defensive ability against external invasion and service life of each system are different.

(1) PE protection parallel steel heading anchor cable

Parallel steel cable-stayed system is hot galvanized epoxy coating (or just epoxy coating) steel wire + both ends heading anchor + hot extrusion PE protection system. After hot galvanizing or epoxy coating, the steel wire is twisted slightly for $2^{\circ} \sim 4^{\circ}$ by special equipment, then wrapped with high strength polyester tape and hot extruded with HDPE casing. After cutting the cable according to the required length, PE and polyester wrapping tape are peeled off at the end, and the steel wire is upsetted after passing through the corresponding hole of the anchor ring. The upsetting anchor structure and real object are shown in Figure 1.

There is a section of steel wire exposed at the end of the cable. The exposed steel wire is the key point of the rust of the cable, which is protected by grouting cement slurry or butter or nothing. It is easy for the steel wire to

rust after water ingress. The typical pictures of exposed steel wire rust are shown in Figure 2. Ten of the bridges surveyed have adopted this system, with an average service life of 10.7 years, which is lower than the average service life of cable. Most of the cable bodies of this type

were built in the 1990s. At present, there are still some bridges in operation, which have great potential safety hazards. It is suggested that they should be replaced in time.

Figure 1. The upsetting anchor structure and real object

Figure 2. The exposed steel wire in upper and lower casing

(2) PE protection parallel steel cold (hot) cast heading anchor cable

This cable system is basically similar to (1). The difference lies in the anchoring device at both ends. For the parallel cable system, after cutting the material according to the required length, at the anchoring part, PE and polyester wrapping tape at the end are peeled off first, then the steel wire bundle is inserted into the anchor cup. The steel wire tail upset is anchored on the back-anchor

plate, and then mixed fillers such as epoxy resin iron shot are poured in section in the anchor cup and connecting cylinder. The cold (hot) cast heading anchor structure and real object are shown in Figure 3.

Compared with heading anchor system cable, cold (hot) cast heading anchor cable is fully sealed. As long as the sealing is not failed, water is difficult to enter. This kind of cable body is the most widely used at present. After years of use, it shows better durability.

Figure 3. The structure and real object of cold (hot) cast heading anchor

(3) High-strength steel strand cable wrapped with steel pipe grouted with cement slurry

The structure of high-strength steel strand cable wrapped with steel pipe grouted with cement slurry is basically the same as that of non-bonded steel strand cable. The common steel strand cable structure consists of anchor rings, clips and anchor backing plates. In order to protect the steel strand, the full-length strand is protected by the steel sleeve and the strand bundles are arranged in parallel. After installation, the strand is tensioned separately or integrally to the designed tension force and the casing is injected with cement slurry. The difference is that, for this system, after adjusting the cable force, the cement slurry is injected into the anchorage steel cylinder. The static load of the cable is borne by the group anchors, while the cement slurry injected into the anchorage steel cylinder bear the second-stage constant load and live load, thus reducing the load of the group anchors, improving the fatigue strength of the cable and improving the rust resistance performance, but it increases the difficulty of replacement.

Six of the 74 bridges surveyed belong to this system of

high-strength steel strand cable wrapped with steel pipe grouted with cement slurry. The average service life is only 9.7 years. Among them, the typical one, Xiaonanmen Bridge in Yibin, adopts the system. The main damage of the suspender of this bridge is insufficient grouting of cement slurry, cracking and water ingress, steel wire rust and wire breakage. It is suggested that the inspection frequency of this type of bridge should be increased, and effective measures should be taken in time to ensure the safety of the bridge if signs of water ingress and rust are found.

(4) PE protection strand extrusion anchor cable

After the whole bundle of external prestressing steel strand is wrapped with PE, the strand is truncated according to the required length. The whole bundle PE and single PE are cut off at the end, and the plastic deformation of the steel bar is produced by extrusion when PE passes through the drilled steel bar. The steel bar is combined with the strand and the extrusion force is generated. The structure and the real object of the whole bundle strand extrusion anchor are shown in Figure 4.

Figure 4. The structure and real object of extrusion anchor

The drilled steel bar is extruded by the steel strand passing through. The extrusion process destroys the epoxy

coating on the surface of the steel strand and makes it easy to rust. At the same time, there is a section of exposed steel strand between the extrusion anchor and the whole bundle of PE. In order to protect this strand, the exposed strand is wrapped with steel cylinder threaded to the extrusion anchor and sealed with rubber sealing ring at the connection end of the whole PE. The steel cylinder is filled with anti-corrosion oil. If the anti-corrosion oil becomes thinner and thinner, it will flow out along the gap between the strands. The steel strands without anti-corrosion oil protection and epoxy coating protection are the same as those in the air, which is prone to water rust.

4 Conclusion

Based on the data of bridges which have replaced cables in China, the durability of cable bridges in China and the rational durability of common cable systems are analyzed. The main conclusions are as follows:

(1) The cable has the characteristics of poor durability and short service time. The average service life of cables in China is 12.5 years, and the service life of cables is mostly concentrated in 4-15 years.

(2) The damage that leads to the durability reduction of the cable is protection damage, water ingress, steel wire rust, wire breakage, wire slippage, anchorage rust, cracking, fire, sudden impact, and so on. The main factors causing the cable replacement of bridges are cable body protection damage, steel cable rust and even wire breakage.

(3) Through the analysis of the rational durability of common cable systems in China, it can be seen that PE protection parallel steel cold (hot) cast heading anchor

cable system is the most widely used cable system in China, and its durability is relatively good. The steel wire in anchor head of PE protection parallel steel cast heading anchor cable is exposed, which is easy to have water rust and has a high safety risk, so it is recommended to replace it in time. The anchorage zone of high strength steel strand clip group anchor cable and PE protection strand extrusion anchor cable are the key points of protection. It is suggested that the inspection frequency should be increased. When there are signs of water ingress or rust, effective measures should be taken to deal with them as soon as they are found.

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