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Application of modern timber structure in short and medium span bridges in China

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Abstract: A series of problems about Chinese bridges with short and medium span recent years were analyzed in this paper. The necessity and feasibility of modern timber structure applied in short and medium span bridges in China were also put forward. The results showed that the short and medium span bridges had many problems, such as monotonous structural forms, serious environmental pollution, multiple bridge defects and difficulty in maintenance. With the development of connection and maintenance technology of modern timber structure and its advantages of light self-weight, environmental coordination, high carrying capacity, excellent durability and abundant structural forms, it was necessary and feasible to apply modern timber structure in short and medium span bridges in China. More emphasis on the construction of modern timber structure should be conducted to expand its application scopes and improve the construction proportion of short and medium span timber bridges.

Key words: short and medium span bridges; timber structure; modern timber bridge; application scope

1 Introduction

At present, the highway bridge construction in China is in a rapid development period. At the end of 2012, the quantity of Chinese highway bridges reaches 713400, including 649000 short and medium span bridges, which account for 90.97% of the total bridges.

Timber bridge has a long construction history in China and plays an important role in Chinese development (Zhou et al. 2011). Timber structure has many advantages: light self-weight, environmental coordination, high carrying capacity, excellent durability and abundant structural forms. In addition, it has wide applications in many countries (Liu et al. 2012; 2013). Therefore, making timber structure applied in Chinese short and medium span bridges will bring great techni-

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cal, economic and environmental benefits.

In order to enrich structural forms of Chinese short and medium span bridges, avoid the material over-reliance on cement and steel, and reduce multiple bridge defects, this paper analyzed these problems and put forward the necessity and feasibility of the application of modern timber structure in short and medium span bridges in China. It is hoped that more emphasis should be conducted on the construction of modern timber structure to expand its application scopes and the construction proportion of short and medium span timber bridges should be improved.

2 Existing problems of short and medium span bridges in China

The quantity of short and medium span bridges in China presents a growing trend year after year, as shown in Fig. 1. They face a series of problems, such as monotonous structural forms, serious environmental pollution, multiple bridge defects and difficulty in maintenance (Li and Sun 2003; Li 2005; Ma 2007; Li 2010; You et al. 2011).

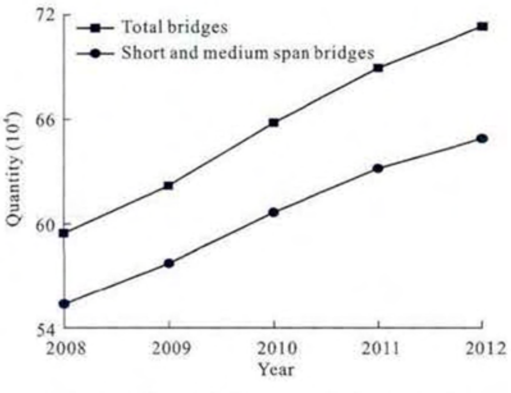


Fig. 1 Quantity of Chinese highway bridges

2.1 Monotonous structural forms

Most of bridges in China are short and medium span bridges, which are usually designed with monotonous forms causing visual fatigue and increasing the probability of traffic accidents. At present, the main structural forms of Chinese short and medium span bridges are plate and beam bridges, such as assembly-type hollow plate assembly-type T girder bridge, assembly-type small box girder bridge and cast-in-place continuous beam bridge, without sufficient bridge, aesthetics.

2.2 Serious environmental pollution

Nowadays, the materials of short and medium span bridges are mainly concrete and steel in China. They consume non-renewable mineral resources and release CO_2 as well as dust in production process. Previous researches show that 0.8 tons CO_2 will be released during per ton cement produced, which is half of steel production. More than 60% of the world's cement is produced in China and the cement consumption per capita per year in China is about 1529 kg, more than four times of the world's average (265 kg) as shown in Fig. 2 (Zhu 2012). In addition, a large number of solid wastes will be produced when the concrete bridges are out of service. With the high-speed construction of short and medium span bridges in China, it is urgent to make full use of environmental materials. Timber is an environmental material for it is not only a renewable material, but also can release O_2 and assimilate CO_2.

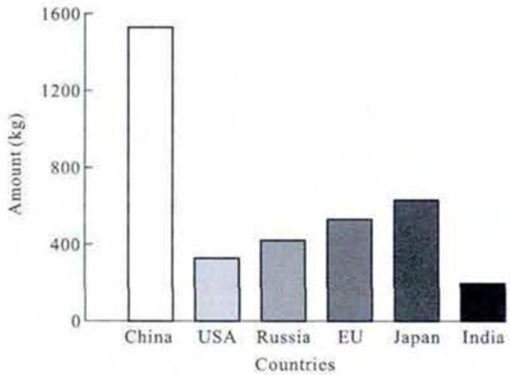


Fig. 2 Cement consumption amount per person

2.3 Multiple bridges defects

In recent years, the destruction and collapse frequently occur in the existing highway bridges. Among these bridges, the proportion of short and medium span bridges is more than 90%. The common problems at present are crack, excessive deflection, steel bar corrosion, the uneven settlement and so on.

Taking hollow slab structure for example, the common problems are hinge joints cracking between precast hollow slab, longitudinal and transverse cracks at bottom of hollow slab, concrete spall, pavement crack and bearing disengaging and so on.

2.4 Difficulty in maintenance

It is important to prolong the service life of the short and medium span bridges by taking some maintenance measures. However, considering the resources, the long construction period, and traffic, there are a lot of problems in the maintenance of concrete and steel bridges.

3 Necessity research

3.1 Question put forward

Timber bridge has a long construction history in China and plays an important role in transportation dating back to ancient. Due to the limitation of materials, timber bridge is the main form of bridge at that time (Mao 1986). For example, the Weihe floating bridge built in 1135 BC, the porous timber girder bridge over the Weihe built in 307 BC, and the gallery road bridge built in 316 BC (Liu et al. 2012). The penetration timber arch bridge, firstly appeared in the Northern Song Dynasty, was not only Chinese unique timber arch bridge, but also Chinese traditional timber bridge form with the highest technology (Tang 2010). The Bianshui Rainbow Bridge (Fig.3), which was painted in the picture of Riverside Scene at Qingming Festival by Zeduan Zhang in the Northern Song Dynasty. The bridge contained 21 groups of arch rib about 40 cm in diameter within the width of the bridge. There were two systems. The first system contained the outside arch ribs with two long and two short member bars and the second system contained the inside arch ribs with three member bars with equal length.

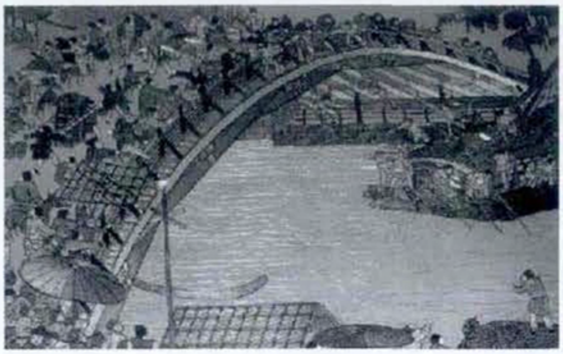


Fig.3 Bianshui Rainbow Bridge

The first modern timber bridge in China is the glued laminated timber arch bridge located in Sheshan golf course in Shanghai, which is a three-pin through glued laminated timber arch bridge with a span of 33 m. What is more, there are some covered timber bridges built at the historical sites in China to reproduce the historical charm recent years. For example, the Qianjiang Zhuoshui Wind and Rain Covered Bridge in Chongqing, as shown in Fig.4, was finished in 2010, whose length was 303 m and width was 5 m. It was the longest covered bridge in Asian. But what is regretful is that it was destroyed on fire in November 2013. Fig.4(b) is the scene of it after fire.

(a) Panoramic view

(b) Scene after fire

Fig.4 Qianjiang Zhuoshui Wind and Rain Covered Bridges in Chongqing

Although China has long construction history of timber bridge, the application of modern timber structure in bridge is relative lag. So it is urgent to catch the attention of relevant departments to improve the application of modern timber structure in bridges, especially in the short and medium span bridges.

3.2 Advantages of modern timber bridge

The rapid developments of population and economy have imposed enormous strains on our environment. How to use the limited and renewable resources effectively and reduce the environmental pollution are the questions that the human society should think about.

Modern timber bridge is a structure with the energy-saving and environment-friendly advantages. At present, China is vigorously promoting the construction of urban and rural traffic. Due to China's wide area of mountains, if the modern timber structures are applied in short and medium span bridges largely, not only will it save cost and shorten the construction period, but also improve and beautify the environment greatly. Developing modern timber bridge will have many advantages. Firstly, it will use more renewable resources and protect the mineral resources. Secondly, it will rich the forms of Chinese short and medium bridges from building materials. At last, it will drive the development of Chinese timber industry and narrow the gap between China and foreign countries in timber process technology.

3.3 Examples of modern timber bridges with short and medium span

Modern timber bridge is popular in many countries, such as Norway, American, Japan and so on. The Alton Sylor Memorial Bridge in American, the Flisa Bridge in Norway and so on are all the successful examples of modern timber bridge (Christopher 2011). The main spans of many timber bridges are larger than 40 m. Maybe modern timber bridge is more suitable for short and medium span bridges. It will have good economic and environmental benefits if the secondary roads, rural roads and overpass bridges could adopt modern timber short and medium span bridges. For example, the Black Dog Halt Bridge, as shown in Fig. 5, is a pedestrian bridge located in southwest England. The glulam arch rib used has a length of 34 m. The Næringa Bridge, as shown in Fig. 6, is a highway bridge with T-beam deck over river in Trysil.

Fig. 5 Black Dog Halt Bridge

Fig. 6 Næringa Bridge

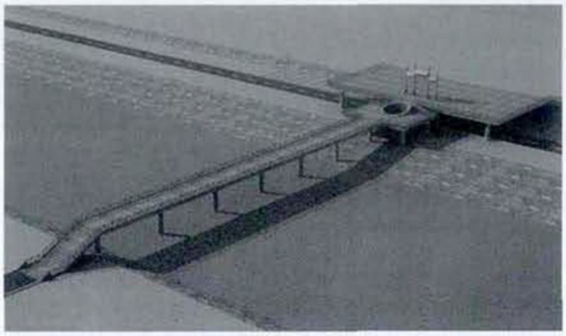
Modern timber bridge construction in China is developing gradually. We take part in the design of a steel-timber composite bridge. This bridge is built in 2011 in Tongchuan, Shaanxi, as shown in Fig. 7. The total length of it is 106 m and the span of it is $(6\times 12)+10+(13+11)$ m. The advanced steel-timber connections and CLT deck are used in this bridge.

4 Feasibility research

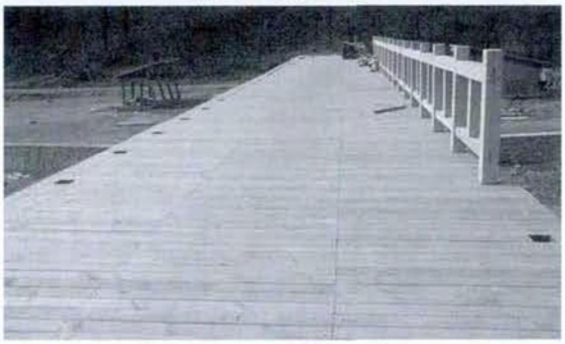
4.1 Technical conditions

4.1.1 Development of timber products

Modern timber processing technology has been successfully applied in timber products processing industry, providing a good opportunity for timber structure used in the field of engineering in China. Nowadays, according to the Technical code for prefabricated timber deck (DB61/T 900-2013), the main timber products that can be used in short and medium bridges include glued laminated timber (GLT), cross laminated timber (CLT), and stress laminated timber (SLT).



(a) Effect drawing



(b) Bridge under construction

Fig. 7 Steel-timber bridge in Tongchuan

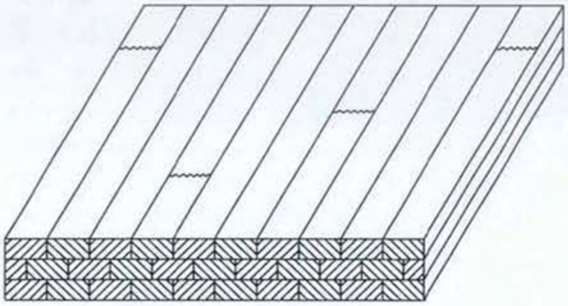


Fig. 8 GLT

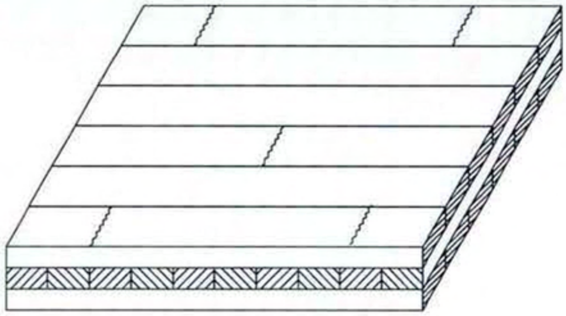


Fig. 9 CLT

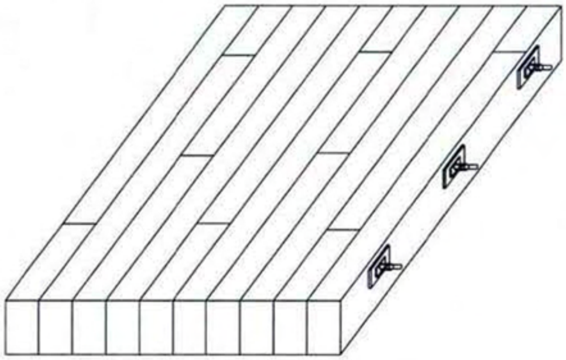


Fig. 10 SLT

GLT, as shown in Fig. 8, can configure different levels of timber according to the stress requirements of timber components at different parts. The timber defects are removed or evenly averaged to all layers. It can be used to produce timber beam, plate or arch. In addition, the lengths and section sizes of the components can be produced without the limitations of timber's natural size, and can be machined into different shapes according to the force-bearing demands. The timber components can be obtained by factorization production, which makes them more diversified and homogenized.

CLT, as shown in Fig. 9, can make full use of the high tensile strength parallel to the grain and high compressive strength perpendicular to the grain of timber. It can improve the integrity, homogeneity and dual direction mechanical properties of timber products. It also can make full use of low grade lumber with high factorization production (Fu 2012).

SLT, as shown in Fig. 10, is an integral plate structure through the lateral compressive stress in the inner layer by tensioning pre-stressed reinforcement. The adoption of pre-stress not only increases its service performance, but also strengthens the connection between the timber components. It can improve the overall service performance, so as to promote the development of timber bridge, especially SLT plate girder bridge.

4.1.2 Diversified connections

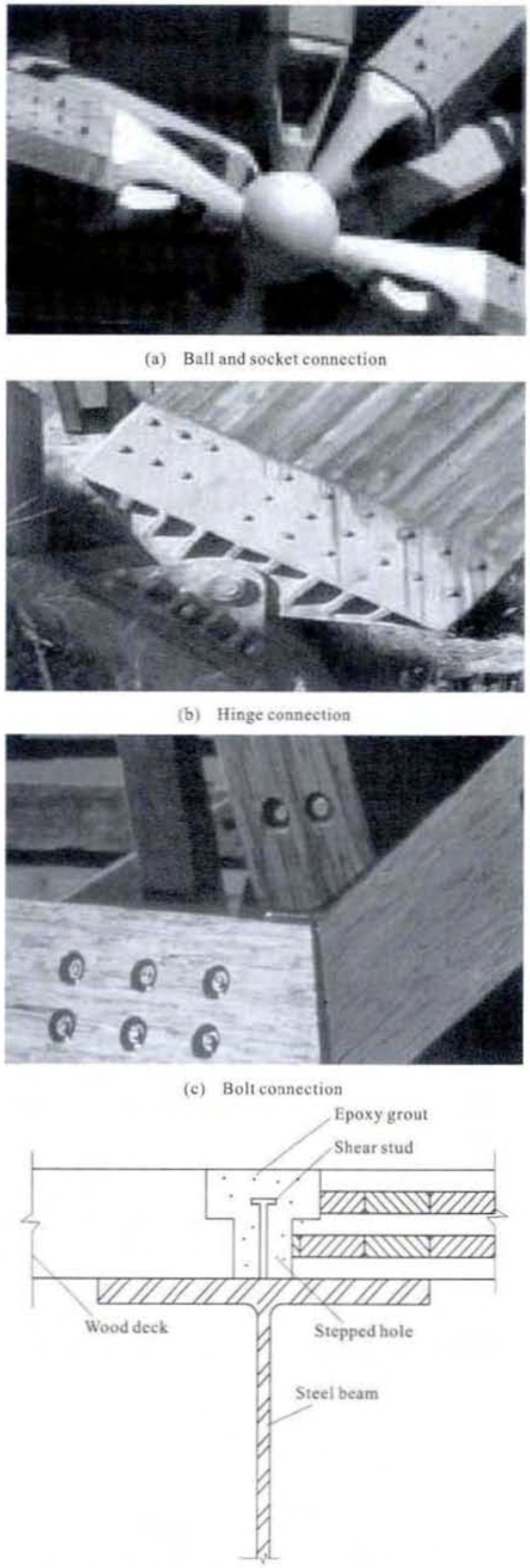
The traditional connections are usually tooth connection, mortise and tenon joint, as well as nail connection and so on. However, the carrying capacity and construction efficiency of these connections are very low, and their fatigue performances are poor. Meanwhile, with the development of modern timber bridge, the span is becoming larger and larger gradually, the demands are improving, and the connection forms are more and more abundant. The ball and socket connection showing in Fig. 11(a) makes it is possible to construct the complex timber truss structures. The hinge connection showing in Fig. 11(b) makes timber arch bridge more popular. The bolt connection showing in Fig. 11(c) realizes the connection of multi-elements, which is safer and more reliable. In addition, some new steel-timber connections are gradually appearing. For example, the connection showing in Fig. 11(d) reduces the installation difficulty during construction, and promotes the development of the modern steel-timber composite bridge (Schneider 2005).

4.1.3 Improvement of the durability

The durability performance of modern timber bridge is greatly improved with the development of modern anti-corrosion and fire prevention technology and the adoption of timber bridge deck surfacing technology.

Firstly, anti-corrosion technology improves the durability of timber bridge. The emergence of modern anti-corrosion technology and preservatives improve the anti-corrosion properties of the timber structure. Meanwhile, its durability has been greatly improved. The quality of timber that treated with preservatives is stabile, economical and wide variety in sources, which can achieve good application and improve the life of modern timber bridge. In addition, related corrosion specifications are also gradually perfected.

The second improvement is from fire resistance. Timber is a kind of biological material, which is composed of numerous tubular cells, and has low thermal conductivity. Meanwhile, there is free water between the cells to reduce the temperature relying on the evaporation of the water. In addition, incombustible gas will be generated when burning process. For the large-size compo-



(a) Ball and socket connection

(b) Hinge connection

(c) Bolt connection

(d) New steel-timber connection

Fig. 11 Connection technology of timber structure nents, carbide layer formed on the surface, will prevent the supply of oxygen. Fireproof property of large size timber structure is as good as other materials components. For example, when the structure suffers with high temperature (15000 ℉), the timber structure will not be destroyed rapidly, but the steel structure will be damaged rapidly due to the sharp decline in yield strength, as shown in Fig. 12 (Ritter 2005).

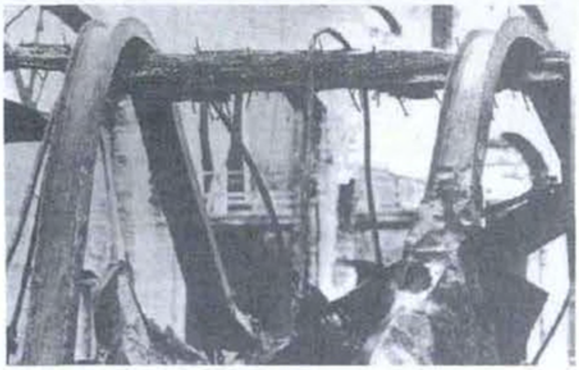


Fig. 12 Steel-timber structure in fire

Thirdly, pavement can improve durability and service performance of modern timber bridge. The asphalt pavement is of good durability and high sliding resistance and used best at present.

4.1.4 Other conditions

After years of theory and application research, timber bridge has rapidly progressed in the developed countries such as the Europe, United States, and Canada. Meanwhile, the relevant specifications are gradually perfected such as Canadian highway bridge design code (CSA CAN/CSA-S6-06), AASHTO LRFD bridge design specifications and so on. They stipulate the calculation, deck design, construction, and other aspects of timber bridge.

There is also some developments of timberwork in China. The national standard code for design of timber structure (GB 50005-2003) implemented in 2004, and the manual timberwork design manual published in 2005 (Long et al. 2005) and so on are all useful to promote the development of timber construction and lead the domestic study of timberwork design.

4.2 Material conditions

The development of timber structure depends on timber resources. Due to the forest protection which has significant achievements after the past fifty years' cycle of deterioration and recovery development, the resources problem has improved and the present situations are as follows:

Firstly, forest area and forest accumulation grow continually. The seventh forest survey data in China shows that the net increase of forest area is 20.543 million hectares, and the coverage rate is increased from 18.21% to 20.36%, up by 2.15%. Net increase of forest accumulation is 1.123 billion m^3 with an annual net increase of 225 million m^3, presenting a good trend.

Secondly, man-made forest grows quickly. The man-made forest area is 62 million hectares now, with a net increase of 8.4311 million hectares. The man-made forest accumulation is 1.96 billion m^3, with a net increase of 447 million m^3. Furthermore, there are 10.4618 million hectares immature forests, providing subsequent reserves of timber in the future.

Thirdly, deforestation is shift to man-made forest gradually, the man-made forest will provide more than 40% of timber we need, and the proportion is growing yearly.

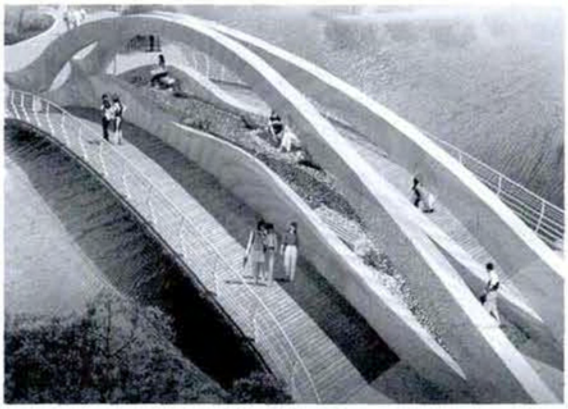
Fourth, amount of imported timber is increasing. The forest accumulation in the world increases about 900 million m^3 each year. There are many countries having enough timber resources, such as Russia having great potential to provide timber to China.

4.3 Application prospect

Compared with concrete and steel structure, modern timber structure has many advantages: light self-weight, higher factorial construction, fast in construction, and good comprehensive economic benefits. It is beautiful and has good coordination with the environment. So its application prospective in Chinese short and medium span bridges will have broad market demand.

4.3.1 Pedestrian bridges

Modern timber structure has good application advantages in the county and overpass bridge. In North America, the middle and small span bridges at second roads or rural roads mostly are timber bridge, achieving good economic and environmental benefits. In China, especially in the regions such as Sichuan and Yunnan which are rich in timber resource, applying the timber bridge as the short and medium span bridges will bring great landscape and economic benefits. Using timber in the pedestrian landscape bridge will give people more warm feeling and completing a high grade structural form of bridge. We used to giving some design schemes of timber bridge for the new campus of an university overpass the lake as a pedestrian bridges. The span of them are all 20 m and two schemes of them are shown in Fig. 13. It can be foreseen that a new bright scenery will be added to this campus because of this timber bridge.



(a) Scheme A

(b) Scheme B

Fig. 13 Pedestrian timber bridge in campus

4.3.2 Bridge in cold region

In cold region, the de-icing salt is utilized frequently, which is commonly composed of NaCl and $CaCl_2$. Therefore, it is easy to cause serious corrosion on concrete or steel bridge. In addition, the seasonal and day temperature changes are very large in cold region, which will produce a lot of secondary internal force and deformation.

To minimize the effects of de-icing salt and temperature change, using timber bridges in cold region can avoid the corrosion damage caused by de-icing salt and reduce the secondary internal force and deformation due to temperature change, so as to improve the service performance and life of the bridge.

4.3.3 Local landmark bridge

Modern timber bridge will play a role of landmark bridge in China with its special material. Taking Xujiang long span timber truss arch bridge "Happy Xujiang Bridge" as an example (Fig. 14), which is located in Xukou Town, Suzhou City, China. The material of this bridge is mainly timber except the pile. And its carrying capacity is 4.5 kN/m^2, and its total carrying capacity is 195 tons. It uses high hardness pine breaking traditional timber architecture concept. The length of this bridge is 120 m with the width of 6 m, and the main span is 75.7 m, which is the largest single-hole span bridge of timber bridge in the world (Lu 2011).

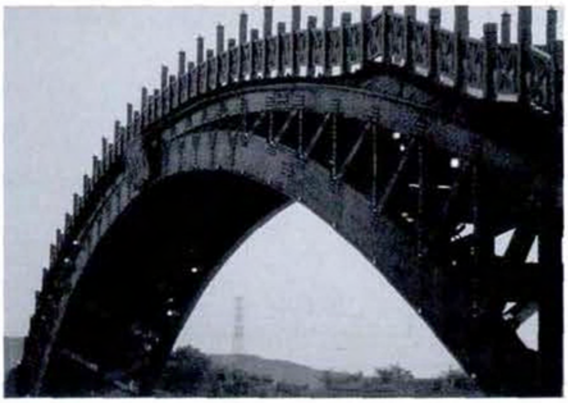


Fig. 14 Happy Xujiang Bridge

4.3.4 Old bridge rehabilitations

It will greatly shorten the construction time and simplify the equipment with good economy by using timber deck to replace the destructive concrete deck in bridge reinforcement. For example, the reinforcement project of Hundrop Bridge in Norway in 2009. It was originally a five-span bridge with concrete deck. During the reinforcement, it used timber deck (CLT deck) to replace the original concrete deck to reduce the dead load of the bridge. It took full use of the original foundation, and reduced the reinforcement costs. The new deck was shown in Fig. 15. It is a good example to apply modern timber bridge structure in old bridge rehabilitations.

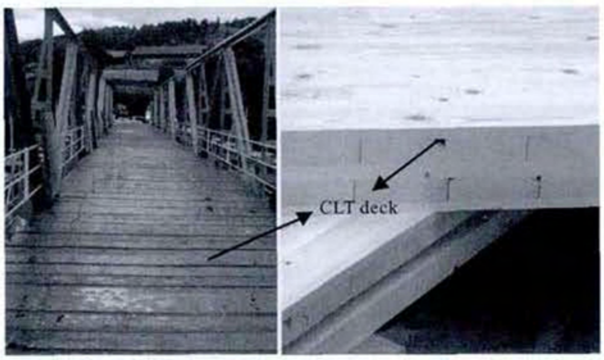


Fig. 15 New CLT deck of Hundrop Bridge

5 Conclusions

Chinese short and medium span bridges face a series of problems, such as monotonous structural form, material over-reliance on cement and steel, suffering multiple bridge defects, and difficulty in maintenance.

Timber structure has many advantages: light self-weight, convenient in construction, green and environmental coordination, and good comprehensive economy. It is necessary and feasible to apply it in the short and medium span bridges in China.

With the development of modern timber structural processing, connection, maintenance technology and the abundant timber resources in China, the application prospective of timber short and medium span bridges in China is broad.

Acknowledgments

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