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Review on the Development of Truss Bridges

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Abstract: Bridges will always be an important project on human beings' development. The society is in continuous decelopment, and the construction never stop, thus, the demand for bridges has been increasing for thousands of years. The bridge which can take more loads whilst using less materials will replace old one. And then the truss structure and truss bridges gradually come into public's view. For the special triangle structure applied on them, the truss structure and truss bridges become of vital important in engineering, using the truss structure on the bridges which have long span can save a lot of money, and because of its special triangle structure, truss bridges can get the same or even more intensity than other bridges in different material. And the development of the truss can be tracked back to the simple wood structure, whilst the current truss bridges use some new materials such as shape memory alloys and modified reinforced concrete. The current study gives an overview on the development history about truss bridges in all ages from China to the world, and will discuss the alternative from material to the structure.

Keywords: Truss bridge, Forth railway bridge, Whipper truss, Howe truss, New materials.

1. Introduction

In the past time, some people considered the truss bridge as a kind of bridge, in fact, it cannot call a bridge type, it is a combination of many different kinds of members. Truss bridges basically use the truss structure, which all the members in the structure are hinged together. So that all the members formed many triangles, and it is well-known that the triangles are the most stable construction in the 2-D structure. The shear force does not act on the members, this special structure transferred the shear force, the stress and the bending moment, which is the most common status into the simple axial tension and compression forces. And because of this special construction, compare different structures in the same length, truss bridges can take more tension and compression, so it can realize a greater bending strength. Whilst bridges in different constructions have the same length, the truss bridges will save more materials.

The evolution of truss bridge change from changing structure or the materials to makes the bridges more intelligent, such as set up the supervisory instrument to monitor the parameter change, thereby obtaining the fatigue and the depletion information of the truss bridges, for that can simplified the process when engineers working on it. The development direction gradually changes from making the bridge safer, to making the bridge convenient for pedestrians and easier to take care and get maintenance at the same time, which can extend the life cycle and then let the building materials to get more effective use.

The first truss structure can be traced back to the 16th century, which is invented by an Italian architecture Palladio, and during that time he begin to use the woods to make truss bridges [1], and that was the earliest truss maintained by the whole text, then it occurred the burr truss and Town truss, whilst the Town truss cannot count as a standard truss structure at present. Then the bridges in the Europe and USA experienced a time that change from the simple triangle derive the truss bridges combine with different constitute, and finally come back to the simple triangle structure. The bridges which suffered the checkout by the time can survive finally. The first Chinese truss bridge appeared during late Qing dynasty, it was founded by woods, called the Old bridge in the past time, but it was destroyed in 1887, now it has been renamed as Huiai bridge. After establishing the state, the demand for the construction in China got a large increase. Science experienced 'epigone' to 'contestant' and finally the "leader", the quantity and quality of the bridges both leapt a lot [2]. Then the trend of designing the truss bridges has begun, and more kind of signature truss bridges occurred in the last few decades.

Studying the changes in structure and materials of truss Bridges from ancient to modern times can tell us what measures architects have taken to enable them to achieve the same or even better function due to changes in climate, loads, natural disasters, etc. Through understanding these knowledges, we can improve the existing truss bridge, considering a variety of factors, under the premise of saving materials and ensuring safety, make its function more perfect, more intelligent.

2. Material and Structural Renewal

2.1. The Development of Truss Bridges' Material

Before 18th century, the material used for building bridges always the one that from the nature, such as the stones and woods, because those kinds of material have abundant resources in the nature, meanwhile, these materials are easy to process and transport, such points are the advantages during the time when the technology had not developed. After The first industrial Revolution, with the rapid development of metallurgy and the demands for the railway and the bridges grow rapidly, the age which using woods and stones replaced by the iron, which is lighter and have higher strength.

The most primitive truss bridge was made of woods, it was designed by an Italian architect Andrea Palladio. According to Heyman, the Cismone was the raging river which will meet the Brenta, every year some piers of the bridge on that river will be carried away by the foods [1]. And because of that, Palladio improved the truss structure used to making roof of

the church and built such a bridge which existed for about 50 years. This single span bridge got 100feet in length, all the members on that got 300 x 225mm, but in structure it is not a simple truss, in fact, it is a composite which combined the truss and other frame structures.

The material changed of truss bridge changed from woods to the iron profits by 2 vital developments of technology. In 1709, Abraham Darby successfully improved the inner diameter of blast furnace to let it fitter to the coke, the set up a new blower, finally found out the new method to fix the problem that the coke inadequate combustion, and further solved the fuel shortage. Meanwhile, in 1754, the UK found the first still mill, it boosted the efficiency of processing the iron. After many years, in 1840, Whipper designed his first bowstring iron truss bridge, and got the patent [3], in his patent, he claimed that this kind of truss bridge can be built to connect the wood floor, and have enough standability, there is no need to depend on the other materials such as stones and the woods. And the method of joints had been invented by him, which is still in use nowadays. Finally, The Whipple iron arch Truss Bridge had been found in 1869, the whole bridge all made by the cast iron and the wrought iron, which has the span of 33.5m, and 7m in width. The appearance of that bridge marked the building material of bridge changed from the time of wood to the age of the iron.

Nevertheless, the emergence of the Forth railway bridge heralding the beginning of using the stell as bridge material, and the cast iron bridge fading away from the public's sight. An engineer named Thomas Bouch once undertook the designing of booth the Tay Bridge and the Forth bridge. Nine years before the Forth bridge completed, a terrible catastrophe just happened, the Tay bridge over the firth just toppled down, and caused an accident which took a train with 73 people into the roaring waves during a storm day [4]. There are three main reasons why the longest bridge that time collapsed. The initial one is the bridge is made by the cast iron and the wrought iron, the tensile strength for the cast iron is smaller than the wrought iron, and the combination of the two materials did not appropriate which increase the fragility of the structure. In addition, the most important thing is about the profit, to the cost saving, the designed structure had been changed. Other statement said that it is about the wind force, because the technology did not enough, the actual wind force act on the bridge is far higher than the designed force. After the Tay bridge collapsed, Bouch had been removed from building the Forth bridge, shortly after that, he passed away and took placed by Benjamin Baker and John Fowler. They aimed at using new technology and materials to connect the two coasts, and make the main railway straight from Aberdeen to Edinburgh [4]. The engineers abandoned the 'Aesthetics is the initial' to the 'function is the first'. Compared with other huge buildings at the same time, the Forth used the low carbon stell as the material, which has a medium tensile strength and the tenacity, and the design philosophy take the reference of the Chinese Magpie nests bridge.

Finally, it had been finished at 1888, include 2 main spans, 2 side spans and 2 approach Bridges with 15 spans. The main body of the three bridge towers 110 meters high, supported by granite piers. Each tower has two arms, each of them got 207 meters long. The arms that form the main span are butted with 107 meters long hanging beams, making the span 521 meters. It was the longest span bridge in the world, the record of it never be broken until the completed of Quebec Bridge in 1919. With the king driving the gold nail into the bridge in 1890, the Forth bridge officially welcomed the open to the traffic, until today it still be in used. As Pinsdorf conclude, the catastrophes not just remain the great problems, in fact, it led to the myth and the way of thinking about questions [5]. If the tragedy of the Tay bridge never happened, then the appearance of this magnificent Forth truss bridge will become impossible, for it have tightest conception and had been overengineered, and the age that the building material of bridge developed from iron to the steel would be delayed years no one knows. It is commonly said that the rapid development of the bridge engineering in USA was started by the rise of the railway, using steel and use of theoretical mechanics to guide the bridge design marked the bridge construction turn to the modern time. And it can be explained the Forth bridge witnessed the bridge engineering transition from modern to contemporary era.

After 7 years, a Chinese politician Hongzhang Li visited the UK and this bridge, he wanted to build a similar in China. Afterwards, Tianyou Zhan suggested a scheme of Wuhan Yangtze River Bridge, and the blueprint of that was imitate the Forth bridge.

2.2. The Development of Truss Bridges' Structure

The most primitive bridge is the single-plank bridge, which is a kind of beam bridge, the earliest possible date can be trace bank to the 1300 BC, which is the Yin dynasty of China. If people want to across some deep river or the valley, make pier under the bridge seems not possible, then the principle of triangle stability applied on the roof was discovered and applied on the bridges. According to the life experience, the ancients add a single column or two columns under the bridge, it was now called the King post truss and Queen post truss, and these two trusses structure were the fundamental types of trusses, other types all change based on these.

The two basic trusses mentioned above do not have big alter before 19th century, as the American historical engineering records collection of summarized truss structure forms, there only exists two kinds of trusses, the Burr truss and the Town truss. As Knapp announced that the earliest Burr truss bridge was founded in 1804 across the Hudson River by Theodore Burr [6]. This bridge is an arch truss bridge with the combination of 3 arch trusses. It was covered 10 years after built, if the fire not burnt it in 1909, it may exist for a longer time. For the burr truss possess the prototype of the modern type, Theodore Burr is known as 'the father of the USA truss bridge'.

Benefit from the first industrial Revolution, the years around 1850s was the golden age of the bridges, during this time, Howe truss and Fink truss are invented. Howe used cast iron replaced the timber for the truss vertical rods, simplifying the complex mortise connections at the joints, meanwhile, it improved the life of the truss bridges. In addition, threaded rods were used in Howe, and two sides of it use the nut to fix, that makes the member adjustable, so the deformation of the truss can be recovered. Because of that, Howe truss is acknowledged as the crowning achievement of wooden truss.

Moreover, the truss bridge used most commonly in contemporary era would be the triangle truss, also known as Warren truss after 2003. As Guise mentioned that this kind of repetitive triangles truss structure initially used by Italian, and finally spread to England [7]. In 1848, James Warren gained the paten in England, for the construction of this bridge firstly used in England, the Warren truss was become the synonym

of this type of the multiple triangles truss. And in 1851, Newark Dyke bridge with 77 meters in length and 11,25 meters in width had been used to carry the railway trucks.

2.3. The Truss Bridges in The Future

In recent years, scholars have been working on using new materials for all kinds of buildings. In terms of truss bridge, new materials such as steel tube truss bridge, steel - concrete truss bridge have been researched. As this kind of truss combined the good points of both the steel truss bridge and concrete bridges [8]. Compared with general steel truss bridges, this kind of truss have stronger stiffness. Beside that, the building debris can be recycled and travel into the building process of other constructions. With the age that the train transportation still occupied a lot, using this structure can reduce the cost and have longer life circle.

3. Conclusion

In summary, the development of truss bridges has a long history, the material from the timber gradually replaced by the steel, and in the recent few years, scientists and other scholars still working on excogitate the new materials and structure to make the truss take more loads and save money at the same time. During the 19th century, the bridges and the truss bridges into a stage which booming growth, that is because the two times of the industrial revolution brought the abundant demand for the railways, the material have higher strength improve continuously, and engineers become more professional, they do not use the life experience as the reference to building the structures, they using more scientific method to design.

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