Life Cycle Cost Analysis of Medium and Small Span Steel-Concrete Composite Bridges in Jiangxi Province

Dai Li\textsuperscript{1,2}, Zhu Zewen\textsuperscript{1}, Jiang Xianglin\textsuperscript{2}

\textsuperscript{1}.Jiangxi Transportation Institute, Nanchang China
\textsuperscript{2}.Research and Development Center on Technologies and Equipment of Long-span Bridge Construction Ministry of Transport, PRC, China Jiangxi Nanchang

Corresponding author:dlwhut2012@163.com

Abstract. This paper investigates the structural form, scope of application, construction technology, management and maintenance measures of steel-concrete composite bridges. Then based on the construction conditions of highway bridges in Jiangxi Province, life cycle cost of steel-concrete composite bridges is analyzed. The economics of short and medium and span steel-concrete composite bridges and concrete bridges are compared from the perspective of life-cycle cost.

1. Introduction
The definition of medium and small span Bridges varies from country to country. According to the general specification for highway bridge and culvert design in China, Bridges with single span of 5-20m are small span Bridges, while those with single span of 20–40m are medium span Bridges. The American small span steel bridge alliance stipulates that the maximum span of small span bridge is 140 feet, and the design guide for New Zealand composite beam bridge stipulates that those with span of 5–30m are small span Bridges and those with span of 30–80m are medium span Bridges. In this paper, the bridge with single hole span between 5 and 40m is introduced as medium and small span bridge.

Nowadays, prestressed concrete structures such as precast prestressed concrete box girders, precast prestressed concrete T-beams and hollow slabs are used for medium and small span bridges (the span is no more than 40m) in China. Nearly 800,000 Bridges have been built by the end of 2019, while the total number of steel structure and steel composite structure Bridges is less than 10,000, it’s less than 1% of the total number of Bridges. With the improvement of steel production capacity and the progress of steel structure bridge construction technology, China now has the material and technical conditions to popularize steel and steel composite structure Bridges. Moreover, the cost, low-carbon environmental performance and durability advantages of steel structure bridges are more prominent from the perspective of the life cycle.

In this paper, the structural form, applicable scope, construction technology, management and maintenance measures of steel structure bridges at home and abroad are investigated. Combined with the construction experience of steel plate composite girder bridges that have been popularized in China, the usage status and maintenance cost data of steel composite bridges under various conditions are obtained. Based on the construction conditions of highway bridges in Jiangxi Province, the paper analyzes the total life-cycle cost of steel and concrete composite bridges in order to compare the
economic efficiency of small and medium span steel and concrete bridges from the perspective of life-cycle cost.

2. Applications of Small and medium span steel composite bridges
The main structural forms of medium and small span steel bridges are steel plate composite beam bridges and grooved steel box composite beam bridges. Steel plate composite beam bridge has good structural performance and durability, the construction difficulty is not only small, and the construction progress is fast, the diversified structure can adapt to the different conditions, the simplified structure reduces the bridge construction and maintenance management workload. With the popularization of industrial construction technology, less girder and simplified stiffener can reduce the comprehensive cost of steel composite girder bridges, which is the development trend of composite girder bridges. Figure 1 is the statistical graph of medium and small span bridges for span and bridge types.

![Figure 1. Statistical graph of medium and small span composite girder bridge.](image)

In foreign countries, there are many practices for the composite beam bridge with few main girder. Since the late 1980s, the research and design of composite beam bridge have been focused in France, and the traditional steel plate beam bridge have been simplified to the greatest extent, and the steel beam bridge with 2 steel main beams has become the mainstream of the application of small and medium span bridges. After years of engineering practice, New Zealand and Japan have also issued design guidelines for I-beam composite bridges, which recommend the use of double or multiple I-beam composite beams.

The application of steel plate composite beam bridge in China is still in the initial stage, and the application quantity of highway bridge is few, mainly in the small and medium span bridges, such as the ramp bridge, approach bridge and flyover structure. Compared with the developed countries such as Europe, America and Japan, there is still a lack of complete design guidance system in China, and it is difficult to grasp the reasonable design parameters, which greatly limits the promotion and application of this type bridge in China. With the release of the guidance on promoting highway steel structure bridges issued by the Ministry of transport, various provinces and cities have actively carried out the research and application of steel plate composite beam Bridges, which have been applied in Anhui, Zhejiang, Guangdong, Hunan, Shaanxi and other places.

The steel box composite beam has obtained great development due to its characteristics of good integrity, torsional resistance, suitable for curved lines and better adaptability to large span and special requirements. Combined steel box girder with grooved steel beam is the most commonly used form of small and medium span composite steel box girder bridge with simple structure and definite load conditions. This section is only combined with the upper flange plate outside the web with the bridge panel. The two sides of the bridge panel are cantilevered without steel stiffener and diagonal brace. The bridge panel is the transverse load-bearing plate. When this type of section adopts transverse prestress, the bridge deck width can be up to about 20m.
3. Construction cost analysis

Taking the Yi-sui highway project as a sample, the construction cost composition and unit price of steel plate composite girder bridge and steel box composite girder bridge with a span of 20~40m are calculated, as shown in Table 1.

Table 1. Average construction cost of steel composite girder bridge in Jiangxi Province. (Yuan per square meter)

| Type                  | Span/m | Technical-economic indicators | The upper structure Economic indicators | The lower structure Economic indicators |
|-----------------------|--------|-------------------------------|----------------------------------------|--------------------------------------|
| Steel composite beam bridge | 30     | 6005.7                        | 3895.6                                 | 2110.1                               |
|                       | 40     | 6567.8                        | 4968.5                                 | 1599.3                               |
| Steel box composite beam bridge | 20      | 8923.4                        | 6521.3                                 | 2402.1                               |
|                       | 30     | 8806.5                        | 6453.6                                 | 2352.9                               |
|                       | 40     | 9013.2                        | 7657.8                                 | 1355.4                               |

The characteristics of steel plate composite beam bridge are the double main beam, less main beam, less transverse support, less stiffening and simplified structure, which can save materials and reduce the cost. Application of steel composite beam bridge structure in Jiangxi province include type I steel composite beams (support beams, block prefabricated bridge panel), type II steel composite beams (the support beams, full width prefabricated bridge panel) and type III steel composite beam (three main girder, the support beams, composite cast-in-place bridge panel).

According to the general diagram of highway bridges and the atlas of steel composite beams in the literature, it can be obtained that the concrete content of steel composite beams is 1/3~1/2 of that of T beam bridges and small box girder bridges. The steel consumption is about 1.5 times than that of T beam bridge and small box girder bridge, as shown in Figure 2.

The amount of steel used for web and floor of steel composite beam is more than that used for web and floor of T beam and small box girder, but the web and floor of steel composite beam saves a lot of concrete. The steel and concrete consumption of the bridge panel of steel composite beam is basically the same as that of the roof of T beam and small box girder, as shown in Figure 3. Considering the material recovery, the steel consumption of steel plate composite beam bridge is greatly reduced, which is about 30% of the concrete bridge.

The above analysis shows that, considering only the amount of steel and concrete and other major materials, composite beams are more competitive than hollow slab beams, T beams and small box girders, and considering the rising labor costs and the overall falling steel prices in recent years, the economic advantages of small and medium span composite beam bridges will be increasingly prominent.

Figure 2. Comparisons of material amount among T girder, small box girder and steel plate composite girder
Figure 3. Comparison of steel amount after considering recycling

Through the structural optimization of steel plate composite beam bridge, the structural stress characteristics are considered, the mechanism of the structure is fully understood, and the amount of steel used is reduced to reduce the cost. On the other hand, we should also recognize its industrial construction requirements, reduce the segment types, simplify the steel beam structure, improve the convenience of steel beam factory manufacturing to reduce the cost. In addition, the superstructure of steel composite beam bridge is much lighter than that of concrete beam bridge, It is also a good idea to explore the economic advantage of steel plate composite beam bridge from the optimization of the lower structure.

Based on the experience of other provinces and the characteristics of Jiangxi province, the following suggestions are put forward to improve the economy of steel plate composite beam Bridges in Jiangxi province. The first point is that considering the climatic characteristics of Jiangxi province, the use of weathering steel is more reasonable, because it can not only reduce the service period maintenance workload, but also can reduce the life cycle cost. Secondly, it can be considered to develop fabricated substructure, which can greatly reduce the cost of steel bridge and promote the industrial construction of highway bridge.

4. Life cycle cost analysis

4.1. Life cycle cost composition
Life cycle cost is from planning, design, construction and service to finally removed and replaced occurs during the life of the total cost, including the organization cost and user cost. Among them, the organization cost is the sum of the planning and design cost, construction and construction cost, maintenance cost and demolition cost, minus the residual value after the bridge is dismantled and recovered

The planning and design cost shall be 3% of the bridge construction and installation fee according to the general design rate. The maintenance cost is divided into daily maintenance cost, preventive maintenance cost and recovery maintenance cost, and the discount rate and inflation rate are introduced into the calculation. In this study, the discount rate and the inflation rate are set at 8% and 5% respectively.

4.2. Life cycle cost of different bridge types
Five kinds of steel composite bridge's life cycle cost in Jiangxi province is calculated, as shown in Table 2 and Table 3. As shown from the table that the design and construction cost accounts for more than 90%, the operation cost accounts for about 7%~9%, and the demolition cost accounts for less than 1% in the life cycle cost.

Table 2. The life cycle cost of medium and small span steel composite bridges.( Yuan per square meter)
| Type               | Span/m | Design cost | Construction cost | Maintenance cost | Demolition cost | Residual value | LCC (Life cycle cost) |
|-------------------|--------|-------------|------------------|------------------|----------------|----------------|----------------------|
| Steel box composite | 20     | 273.0       | 8923.4           | 728.6            | 26.8           | 21.5           | 9930.3               |
|                   | 30     | 266.0       | 8806.5           | 624.3            | 27.6           | 20.7           | 9703.7               |
|                   | 40     | 195.0       | 9013.2           | 575.3            | 26.6           | 21.0           | 9789.1               |
| Steel plate composite | 20     | 177.0       | 5985.3           | 575.6            | 18.5           | 15.8           | 6740.6               |
|                   | 30     | 185.0       | 6005.7           | 587.7            | 17.7           | 13.5           | 6782.6               |
|                   | 40     | 197.0       | 6567.8           | 603.5            | 22.0           | 15.4           | 7374.9               |

Table 3. The life cycle cost of medium and small span concrete bridges. (Yuan per square meter)

| Type               | Span/m | Design cost | Construction cost | Maintenance cost | Demolition cost | Residual value | LCC (Life cycle cost) |
|-------------------|--------|-------------|------------------|------------------|----------------|----------------|----------------------|
| Fabricated box girders | 30     | 118.4       | 3685.1           | 1023.3           | 22.4           | 1.1            | 4848.1               |
| Fabricated T beam  | 30     | 125.6       | 3964.5           | 975.6            | 25.2           | 1.3            | 5089.6               |

5. Conclusions
The life cycle cost of several composite beam bridges is compared. The life cycle cost of 30m steel plate composite beam bridge is the lowest, followed by 40m steel plate composite beam bridge. Compared with the concrete bridge, the steel structure bridge needs less maintenance times in the life cycle, and the maintenance cost is 300~500 yuan lower per square meter. From the perspective of life cycle cost, the economic difference between the two is not as large as the construction cost. If the span, section and section of steel structure bridge are further optimized, the construction cost of steel structure bridge can be further reduced and the economic competitiveness of steel structure bridge can be improved.

Acknowledgments
This paper was supported by Science and technology project of Jiangxi Pro vincial department of Transportation (Grant No:2017C0002,2017H0014). The authors also wish to thank the anonymous reviewers for valuable comments to earlier versions of this paper.

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