The Development and Theoretical Research Analysis of Extradosed Bridge

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Abstract. The extradosed bridge, which began in Japan in the early 1990s, started relatively late in China. The extradosed bridges have the characteristics of rigidity and flexibility, and it accords with the mechanics law of the structure. It has attached more attention and has widely application prospects. This paper first introduces some extradosed bridge built at home and abroad. And then by reviewing current researches about the extradosed bridge, it is found that the theoretical research on this bridge type is constantly emerging. The research results and engineering practice applications mainly focus on the line of main beam, construction control technology and mechanical behaviour research. Finally, it is concluded that the research on the bridge type can further explore and research in the preparation of special design codes, construction technical regulations, calculation theory of concrete shrinkage and creep effects and prestress loss.

1. Introduction

The extradosed bridge, also known as partial cable-stayed bridge, is a new type of bridge structure, which rose in Japan in the early 1990s. In 1994, Japan built the world's first extradosed bridge called the Odawara Port Bridge. The construction of extradosed bridge in China started relatively late. In 2000, Wuhu Yangtze River bridge that is three sections and two towers structure: 180m+312m+180m, was the first extradosed bridge in China.

The extradosed bridges have the characteristics of rigidity and flexibility, and it accords with the mechanics law of the structure. It has attached more attention and has widely application prospects. The extradosed bridge is a transition structural form between the continuous rigid frame bridge and the cable-stayed bridge. It can also be said to be a cooperative system of the cable-stayed bridge and the beam bridge. There are some following distinctive features.

1. Aesthetic landscape features: the beam height of the extradosed bridge is about 1/2 of the continuous beam bridge, with a morbidezza and fine aesthetic effect. It hasn't the feeling of constriction caused by the high beam height of the continuous beam bridge, and overcomes the incompatibility between the substructure and superstructure. Its towers and cables have a magnificent and spectacular feeling of cable-stayed bridges.

2. Flexible arrangement of span: the extradosed bridge can be designed as a single tower with double spans, two towers with three spans and multi tower with multi span structure. The distance of a single span is in the range of 100 to 300m, which overcomes the problem of the insufficient stiffness
of the multi-tower cable-stayed bridge and the interaction of each span. Meanwhile it has the advantages of the multi-span continuous beam bridge, which has a great choice in the design of the single span and the length of the bridge.

3. Simple construction: the extradosed bridge can be constructed by cantilever casting method, which is basically same as the continuous girder bridge. It is not necessary to adjust the secondary cable force during construction. Because the tower of the extradosed bridge is relatively short, the construction of the tower is not complicated as the cable-stayed bridge.

4. Good economy: Based on the cost analysis of the extradosed bridge built at home and abroad, the cost of the bridge type per linear meter is basically equal to the continuous beam bridge and lower than the cost of the general cable-stayed bridge. Consequently, it has considerable economic benefit.

2. Development status of extradosed bridge at home and abroad

2.1 Development status at abroad

When French engineer J. Mathivat designed the Arret Darre viaduct scheme in France in 1988, the prototype of the extradosed bridge was put forward. Although the scheme was not implemented, the impact was far-reaching. At the end of 1980s and early 1990s, after Japanese obtained the Arret Darre viaduct scheme information, the bridge type was studied deeply.

It was believed that it had many advantages in both technical and economic aspects, so the bridge type was actively developed. The most representative extradosed bridge is Odawara Harbour Bridge, which was designed in 1990, completed in 1994, and had a span of (74+122+74) m. Since then, the extradosed bridge has been developing rapidly in Japan. The representative extradosed bridge built abroad is listed in Table 1.

| Bridge Name       | Country   | Span combination       | Bridge Name       | Country   | Span combination       |
|-------------------|-----------|------------------------|-------------------|-----------|------------------------|
| Sunniberg Bridge  | Switzerland | 59+128+140+134+65     | Pakse Bridge      | Laos      | 70+102+9+123+134+65   |
| Odawara Port      | Japan     | 74+122+74              | Pyung—Ye02Gyo     | Korea     | 65+120+65              |
| Bridge           |           |                        | Miyalkoda River   | Japan     | 133+133                |
| Yashiro Bridge    | Japan     | 64.5+2×105+64.2        | Keong—An          | Korea     | 70+130+80.5            |
| Shinkawa Bridge   | Japan     | 90+130+80.5            | Gum-Ga Grand      | Korea     | 85+5+125+85            |
| Kiso River Bridge | Japan     | 160+2×275+160          | Brazil Peru       | Brazil    | 65+110+65              |
| Kani sawa Bridge  | Japan     | 99.3+180+99.3          | Unicom Bridge     | Croatia   | 72+120+72              |
| Saj ika Bridge    | Japan     | 60.8+105+60.8          | Home Bridge       | America   | 75.9+157+75.9          |
| Golden Ears Bridge | Canada  | 121+3×242+121         | New Pearl Harbor  | Palau KB bridge | 82+247+82           |
| Bridge           |           |                        | Memorial Bridge   | Palau     | 82+247+82              |
| Ganter Bridge     | Switzerland | 127+174+127         | Palau KB bridge   | Palau     | 82+247+82              |
| Viaduc de la      | France    | 43+75+105+126         | The Second Vivekananda Bridge Tollway | India | 55+7+110+55 |
| ravine des Trois-bassins |         |                        | Sh i nkawa        | Japan     | 94+3+140+94            |
| Ibi River Bridge  | Japan     | 154+4×271.5+157       | Tsukuhara Bridge  | Japan     | 65.4+180+76.4          |
| Karato Bridge     | Japan     | 66.1+120+72.1         |                   |           |                        |

Note: the data in the table are derived from literature [1]

It can be seen that the extradosed bridge has developed rapidly from the table. The span of the bridge increased from the original 100m to the 275m, and the bridge width increased from 13m to 33m. The structure types varied from the original single cable plane to the double cable planes and three cable planes. The main girder materials also developed from concrete to steel-concrete composite
bridge and corrugated steel webs extradosed bridge. As shown in figure 1, representative examples of extradosed bridge at abroad are given.

![Kiso River Bridge](image1)  ![Miyalkoda River Bridge](image2)  ![Mu Young Bridge](image3)

Figure 1. Examples of extradosed bridge at abroad

### 2.2 Development status in China

The extradosed bridge is relatively late in our country. The first extradosed bridge in China is Wuhu Yangtze River bridge, which is still the largest spans of the extradosed bridge in China. Fujian Zhangzhou war preparedness bridge is the first real concrete extradosed bridge in China, Kaifeng Yellow River bridge is currently the largest number of span and the longest length of the extradosed bridge in the world. Table 2 illustrates some representative extradosed bridge in China. As shown in figure 2, representative examples of extradosed bridge in China are given.

![Wuhu Yangtze River Bridge](image4)  ![Zhangzhou War Preparation Bridge](image5)

Figure 2. Examples of extradosed bridge at abroad

| Bridge name         | Location | Span combination | Bridge name         | Location | Span combination |
|---------------------|----------|------------------|---------------------|----------|------------------|
| Zhangzhou War       | Zhangzhou| 80.8+132         | Kaifeng Yellow      | Kaifeng, | 85+6×140+85      |

Table 2. List of Extradosed bridges (main span ≥100m) built in China
Preparation Bridge | Fujian | +80.8 | River Second Highway Bridge | Henan
---|---|---|---|---
The Yellow River West Lake Bridge | Lanzhou, Gansu | 81.6+136 | Wuhu Yangtze River Bridge | Wuhu, Anhui | 180+312+180
Changzhou Canal Bridge | Changzhou, Jiangsu | 70.2+120 | Songhua River Bridge | Jilin | 95+3×150+95
Lishi viaduct | Shanxi | 85+135+85 | Sifang River Bridge | Yunnan | 2×175
Fen River Bridge | Taiyuan | 90+150+91 | Xugou Bridge | Henan | 82+150+82
Chaobaihe River Bridge | Beijing | 72+2×120+72 | Nanpan River Bridge | Yunnan | 108+180+108
The west auxiliary bridge of the Yellow River bridge in Yu Menkou Hancheng, Shaanxi | 75+2×125+75 | The east auxiliary bridge of the Yellow River bridge in Yu Menkou Hejing, Shanxi | 75-2×125+75
Jialing River double line railway bridge | Chongqing | 118+228+118 | Hui Qing Yellow River Highway Bridge | Binzhou, Shandong | 133+220+133
He Maxi Bridge | Zhuhai | 125+230+125 | Jia Yue Bridge | Chongqing | 145+250+145

3. Status of the theoretical research about extradosed bridge
The theoretical study of the extradosed bridge at its initial stage is mainly about its naming, development and force characteristics. In the past ten years, the extradosed bridge has been developed rapidly, and the theoretical research is also appearing. At present, the research achievements and practical application of the extradosed bridge are mainly studied in the following three aspects:

- Research on the line of the main beam
  Through the analysis of the deflection of the main beam under the shrinkage and creep of an extradosed bridge, Li [2] investigates the influence factors in detail, and points out that shrinkage and creep have the greatest influence on the deflection of the main beam. Finally, 10 measures to reduce the deflection of the main beam are given.
  Zhang [3] analyses the structural characteristics and mechanical behaviour of the extradosed bridge, and illustrates the control of its line shape and engineering quality during the construction process. It is discussed that this type of bridge structure is very competitive in the selection of the bridge structure, and has a good application prospect.

- Research on construction control
  Li [4] investigates in the key technology of construction control for the extradosed bridge. By researching and summarising the key technologies in the construction process, the system of main beam prestressed concrete and stay cables construction technology have been formed.
  Gao [5] takes an extradosed bridge which is a single tower and a single cable plane as an example, and carries out the construction control study. According to the characteristics of the bridge, the internal force and deformation of the bridge are calculated by the finite element program, the key parts of the bridge are determined, and the construction control scheme of the bridge is worked out. Through the construction control practice of the main structure, it can ensure the safety and closure of the bridge in the construction. The bridge alignment and the structural internal force conform to the design requirements, to achieve the purpose of bridge construction control.

- Research on mechanical behaviour
  Wu [6] analyses the bridge type characteristics, the force characteristics and the design key points about the prestressed concrete extradosed bridge. With the help of practical engineering background, the bending moment of the extradosed bridge is obtained. Finally, the optimization method and the optimization target of the reasonable completion state are summarized.
Li used an extradosed bridge with a penetrating anchorage method as the background project, and the spatial finite element analysis model of the extradosed bridge tower was established. According to the equivalent simplified load and boundary conditions, it is loaded to analyze the force characteristics of the type of the extradosed bridge tower, and the distribution of the local dangerous area in the force of the bridge tower is clearly defined.

4. Research prospect

A large number of documents show that most of the current researches on extradosed bridge aim at studying their mechanical properties, or dynamic parameters, and their alignment. There are many references about the construction technology or construction monitoring technology of extradosed bridge. There are few references about the shrinkage and creep effects of the extradosed bridge. Because of its superiority, the extradosed bridge is being built more and more, and the research is more and more. The following aspects are worthy of further exploration and research.

1. There are no pertinency specifications for the design and construction of the extradosed bridge. At present, there is only a mention in the specifications of cable-stayed bridges, so there are some space for the study of design specifications and construction techniques.

2. The mechanism of concrete shrinkage and creep is more complex, which is not completely solved at present. The effect of concrete shrinkage and creep on the extradosed bridge deserves further study. It not only has great scientific value to calculate the theoretical model of shrinkage and creep of concrete, but also has extensive application prospects and great social and economic benefits.

3. The problem of prestress loss is the problem existed in all prestressed bridges, which is difficult to be solved completely at present. The main beam of the extradosed bridge is basically same as the continuous rigid frame bridge. Therefore, for the prestressed concrete structure of the extradosed bridge, the calculation and control of the prestress loss, the long-term deformation and the cable force loss should be further studied, and the relevant regulations of the current specifications are checked.

5. Conclusion

Since 1988, the prototype of the extradosed bridge has been put forward and developed rapidly, and the research on the bridge is constantly increasing and improving.

1. This paper summarizes the construction of some extradosed bridges at home and abroad, and finds that the bridge type develops rapidly, and the span also increases from the initial 100m to more than 300 meters.

2. According to the research literature on the extradosed bridge at present stage, it can be seen that the theoretical research on the bridge type has emerged in recent years, and the research results and engineering practice are mainly focused on the following aspects: the alignment of the main beam, the construction control technology, and the mechanical behaviour research.

3. According to the present research results, it is found that the research on the bridge type can further explore and research in the preparation of special design codes, construction technical regulations, calculation theory of concrete shrinkage and creep effects and prestress loss.

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