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Application of Extradosed Prestressing

Garima Malik[1], Sumit Saini[2], Anjali Malik[3]
M.Tech Scholar[1], Assistant Professor[2], Structure Designer[3]
Department of Structure Engineering[1], Department of Civil Engineering[2]
Gateway Institute of Engineering and Technology Affiliated to DCRUST, Murthal Sonepat, India[1, 2]
Aecom India Pvt. Ltd. Gurugram, Haryana, India[3]

Abstract:
Prestressed concrete (PC) technology is being used all over the world in the construction of a wide range of bridge structures. However, many PC bridges have been deteriorating even before the end of their design service-life due to corrosion and other environmental effects. In view of this, a number of innovative technologies have been developed to increase not only the structural performance of PC bridges, but also their longterm durability. These include the development of novel structural systems and the advancement in construction materials. This paper presents an overview of such innovative technologies on PC bridges on their development and applications in actual construction project.

Keywords: Prestressed concrete bridges, external prestressing, extradosed bridge, corrugated steel web, pre-grouted prestressing tendon

I. INTRODUCTION

The intrados is defined as the interior curve of an arch, or in the case of cantilever-constructed girder bridge, the soffit of the girder. Similarly, the extrados is defined as the uppermost surface of the arch. An extradosed prestressing concept, which was first proposed by Mathivat in France ,is a new type ofstructural system in which the tendons are installed outside and above the main girder and deviated by shorttowers located at supports. Considering its definition, this type of bridge is placed between cable-stayed bridges and ordinary girder bridges with internal or external tendons. Extradosed PC bridges have several positive characteristics. The girder height may be lower than that ofordinary girder bridges, thus reducing self-weight of structures. As shown in Figure 1, the ratio of the girderheight to the span length (H/L) in extradosed bridges ranges between 1/15 and 1/35, while it is approximately 1/15~1/17 for box-girder bridges. Comparing to cable-stayed bridges, the height of the main tower in extra-dosed bridges is lower; hence, a reduction in labor costs of construction can be achieved. Because of a lower main tower in extradosed bridges, vertical loads are partly resisted by main girders and stress variations in stay cables produced by live loads are smaller than those in cable-stayed bridges. This is quite similar to the behavior of box-girder bridges, where the main girder itself has a decisive influence on the structure rigidity and live loads produce only limited stress variations in tendons. Based on these facts, the Ja- pan Road Association has recommended that the safety factor for the stayed cables in extradosed bridges under design loads shall be taken as 1.67 (0.6 fpu; fpu = tensile strength of tendons), which is same as that fortendons in ordinary girder bridges. For cable-stayed bridges, this value is specified to be 2.5 (0.4 fpu).The major difference among box-girder, extradosed and cable-stayed bridges can be further revealed by comparing the relationship between materials used with span lengths. In box-girder bridges, the average concrete thickness increases with the span length, since the girder height is a function of the span length. On the other hand, in cable-stayed bridges, there is almost no increase in the average depth of concrete because the girder height is generally designed to be 2.0~2.5 m, regardless of the span length. It is interesting to note that extradosed bridges are placed between these two types, and the rate of increase is also thought to be midway between the rates of the other two types of bridges. Similarly, with increasing span length, the quantity of prestressing tendons in box-girder bridges shows amore increase than that in cable-stayed bridges, whereas extradosed bridges yield the intermediate value between the other two types. From the above discussion, it can be concluded that an extradosed bridge is similar in construction and appearance to a cable-stayed bridge. In the light of structural properties, however, an extradosed br idge is closed to ordinary PC girder bridges, and the design specifications may be considered to be the same f or both types of bridges.

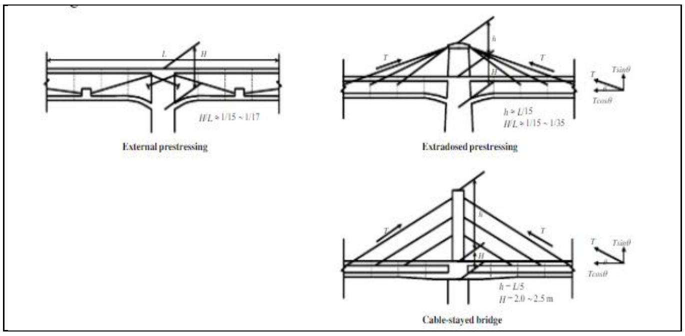

Figure.1. Comparison among externally box-girder, extradosed and cable-stayed PC bridges.

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II. DIFFERENCE BETWEEN CABLE-STAYED BRIDGES AND EXTRADOSED BRIDGES

The differences between cable-stayed bridges and extradosed bridges have being debated by numerous researchers. Both types of these bridges have structures that use stay cables as reinforcements. However, in case of extradosed bridges it is necessary to provide a structural rationale rather than simply assuming an allowable stress of 0.6fpu in design of the bridges. In this point, attention focuses on the distribution ratio of vertical load carried by the girders and the stay cables. Figure 2 shows the relationship between the distribution ratio of vertical load (β) and maximum stress change of stay cable due to design live load (ΔσL)of various cable-stayed bridges and extradosed bridges. As shown in the figure, it is difficult to clearly distinguish between extradosed bridges and cable-stayed bridges in terms of structural mechanics since many of the cable-stayed bridges are very similar to extradosed bridges. In designing stay cables, stress change due to design live loads provides an effective index that can be easily determined through the design process.

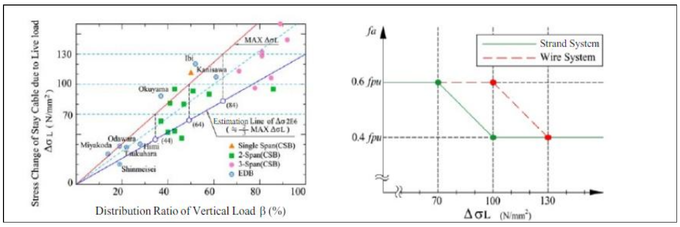

Figure.2. Distribution ratio of verticalload and stress change of stay cable.

III. APPLICATION OF EXTRADOSED PRESTRESSING

Nowadays, a great number of PC bridges using extradosed pres tressing are being constructed in Japan.Attempts are also being made to apply this structural concept to other innovated technologies, such as corrugated steel web, precast segmental construction, and combined structures with steel girders. Figure 3 shows the Odawara Blue-Way Bridge, which is the first extradosed PC box girder bridge in the world and was completed in 1994. This bridge was designed with a three-span continuous box-girder withextradosed prestressing, having a middle span length of 122 m, a tower height (h) of 10.5 m, and a girder height at supports (H) of 3.5 m. The ratios of h/L and H/L are approximately 1/12 and 1/35, respectively. Figure 3 shows the prospective view of the Shin-Meisei bridge on Nagoya Expressway No. 3 crossing theclass-1 Shonai River in western Nagoya. From both aesthetic and economic viewpoints, the bridge was designed with a three-span continuous rigid-frame structure with extradosed prestressing, which is to become a landmark of Nagoya's western threshold. The length of the middle span (L) is 122 m, a tower height (h) of16.5 m, and a girder height at supports (H) of 3.5 m, giving the ratios of h/L and H/L of 1/7.4 and 1/35, respectively

Figure .3. Odawara Blue Way Bridge(3-span continuous extradosed PC Bridge)

Figure.4.Shin Meisei Bridge(prospective view) (3-span continuous extra dosed PC bridge)

IV. CORRUGATED STEEL WEB AND ITS APPLICATION TO BRIDGES

In PC bridges with corrugated steel webs, light-weight corrugated steel plates are used instead of concrete webs. The corrugated steel plate webs are capable of withstanding shear forces without absorbing unwanted axial stresses due to prestressing, thus enabling efficient prestressing of top and bottom concrete deck slabs, thus resulting in an “accordion effect” (Figure 5). Moreover, the corrugated webs also provide high shear buckling resistance. Use of light-weight corrugated steel plates for webs causes a reduction of self-weight of about 25% of main girders. Therefore, this enables the use of longer spans and reduction of construction cost. The weight of a segment to be cantilevered during erection can also be reduced, thus longer erection segments can be adopted and construction period can be shortened. This also eliminates assembly of reinforcement, cable arrangement and concrete placement for concrete webs. Thus, saving of construction manpower, quality enhancement and improvement of durability are expected. In addition, replacing the damaged deck slabs is easier than that in ordinary PC bridges.

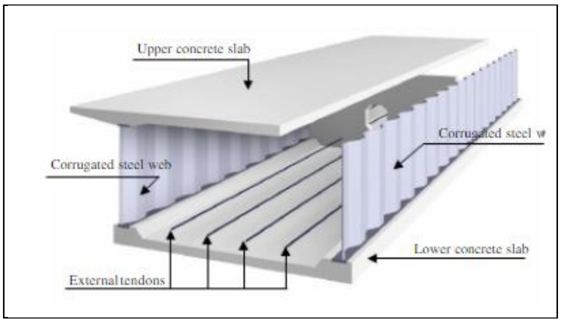

Figure.5. Typical section of PC Bridge with corrugated web

V. APPLICATION OF INNOVATIVE TECHNOLOGIES IN PC BRIDGES

The state of art technologies described in this paper with regards to the structural system and construction ma-terials have already been implemented in PC bridges in Japan. Some of the noteworthy structures, which rep-resent the state-of-the-art technologies in the construction of PC bridges in Japan are presented here.

Kiso and Ibi River Bridges

The Kiso River and the Ibi River Bridges were constructed as a part of the New Meishin Expressway that will connect Nagoya and Kobe. The 1,145m long Kiso River Bridge (Figure 6) and the 1,379m long Ibi River Bridge (Figure 7) are located approximately 1,300m apart, crossing the two major rivers. The total width of both bridges is 33m, accommodating 6 traffic lanes. The center and the side spans are over 270 m and 150 m, respectively. The extradosed PC bridge type and steel composite girders were selected to cope with such long spans, taking economy, construction time and workability into consideration. This is the most unique feature of these bridges, making them the world's first extradosed bridges with a composite structure. Steel girders were used in the central sections of approximately 100 m to reduce the weight of superstructure, while high strength concrete girders were used for the remaining sections. Further reduction of the dead load is achieved by placing some of the tendons externally inside the box girder section, which makes thin webs possible. The precast segment method is employed for the concrete sections of the girders. Each segment with weight of 300 to 400 ton is precast using high strength concrete of 60N/mm 2 by the short line match casting method in the fabrication yard located about 10 to 15 km away from the project sites. The segments for the main girders are transported to the sites by ship and placed into position by large temporary facilities, such as erection noses and erection trusses except the pier head tables, each of which was divided into three and in-stalled by a 600 ton floating crane. The steel girder sections, which weigh about 2000 ton each, are fabricated in a factory and transported to the sites and then erected at one time by reaction girders attached to both ends of the concrete girders after completion of the concrete segments installation. The construction of the Kiso and Ibi River of extradoses prestressing could be successfully applied to longs pan Bridges Having composite structures. Based on the creation of standards and experience up to now, the extradosed PC bridges, streamlined in terms of both structural properties and economic considerations, will undoubtedly continue to develop in the future.

Figure.6. Kiso River Bridge

Figure.7.Ibi River Bridge

VI. CONCLUSIONS

Recent techniques in design and construction of PC bridges in Japan were presented in this paper, with emphasis on their background and development as well as their applications in actual structures. Not only to improve the structural properties in terms of safety, aesthetic and economical aspects, such innovated technologies were developed to enhance the long-term durability, which is becoming one of the serious problems in concrete structures nowadays. In light of new structural systems, external prestressing with highly eccentric tendons and extra dosed pre-stressing are excellent examples of a wider use of external prestressing technology to achieve a PC bridge with improved structural performance as well as cost-effective outlook. The corrugated steel webs, which take advantages of steel and concrete, have proved to be one of promising solutions that can reduce the self-weight of main girders, thereby enabling the use of longer spans and reduction of construction cost

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