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Comparisons of Design Schemes for the upper beam support at east cable tower of Lingdingyang Bridge on Shenzhen-Zhongshan Link

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Abstract. The complex site conditions of Lingdingyang Bridge on Shenzhen-Zhongshan Link lead to many construction difficulties. The design of the support affects the construction quality of the super-height, large-weight and long-span beam on the cable tower. In order to achieve a high-standard construction and control the quality of the project, three support design schemes for the upper beam of the east cable tower of Lingdingyang Bridge were studied and compared by calculating and analyzing with the finite element software. Ultimately, the plan of the upper arch bracket stands out among the three schemes. The bracket scheme can not only meet the quality requirement of the main structure, but also reduce the construction difficulty and cost of the temporary structure, which can provide reference for the design of similar projects in the future.

Keywords: Shenzhen-Zhongshan Link, cable tower, upper beam support, comparisons.

1. Introduction

Shenzhen-Zhongshan Link is the first cluster project in the world integrating ultra-wide and ultra-long submarine tunnels, super-large cross-sea bridges, deep-water artificial islands and underwater interchange, with unprecedented scale and technical difficulty [1]. Shenzhen-Zhongshan Link (Shenzhong Link) connects Jihe Expressway in the east, crosses the Pearl River Estuary, and reaches Zhongshan Maanshan Island in the west. It is joined to the planned Zhongkai Expressway and the Eastern Outer Ring Expressway, and lands in Shenzhen, Zhongshan and Nansha in Guangzhou. Shenzhong Link is about 24km long, among which the sea crossing section is 22.39km long. The project adopts the technical standard of eight-lane expressway in two ways with a design speed of 100km/h.

The key route of Shenzhong Link is Lingdingyang Bridge. Lingdingyang Bridge is a 580m+1666m+580m three-span full floating suspension bridge, which is one of the largest suspension bridges in the world. Because the bridge deck is up to 90 meters high, when completed, it will be the world's highest bridge in the sea, and its comprehensive scale and difficulty are greater than those of similar projects in the world [2]. The cable tower adopts a portal shape, and its main components include lower tower columns, middle tower columns, upper tower columns, upper beams, middle beams, lower beams, tower crowns, etc. The main structure of the east cable tower is shown in Figure 1. The bottom elevation of the east main tower columns of Lingdingyang Bridge is+0m with a total height of 270m. The design elevation of the upper beams is from +251.826m to +262.500m. See Figure 2 for the structure diagram of the upper beam. The upper beam requires 2248.8m³ C55 marine concrete and 521.1t HRB400 ordinary reinforcement. The design for this height, span and weight of the uppercross beams of the main tower is rare in domestic project, so the process of the design and construction is complicated and difficult [3].

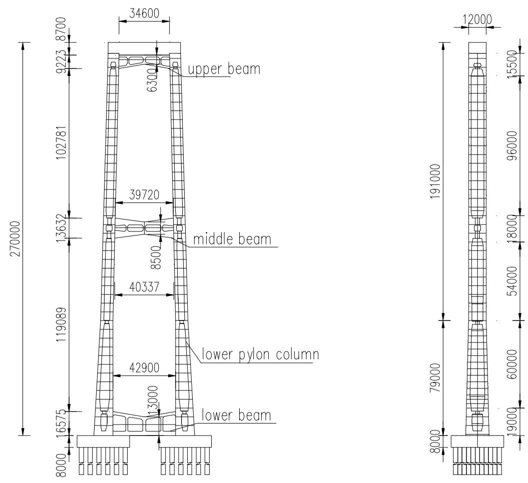

Figure 1. The structure of the east cable tower on Lingdingyang Bridge

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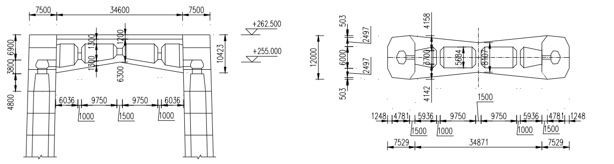


Figure 2. The structure of the upper beam at the east cable tower on Lingdingyang Bridge

2. Design Schemes

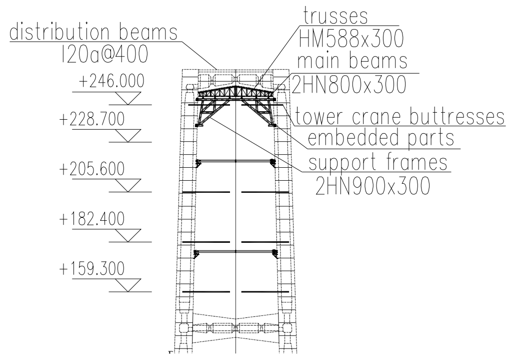
The upper beam support of the cable tower is one of the most important temporary structures in the construction. It must have sufficient strength and stiffness, and attention should be paid to the detailed design of the structure. At the same time, the construction method of the support and the safety in the construction process are also very important [4]. Therefore, it is particularly significant to select the design scheme of the upper beam support of the tower and obtain the optimal scheme which is safe, economical and reasonable and convenient for construction.
For the sake of preventing the concrete from producing stable cracks, the upper crossbeam is cast in situ, and it is considered to be cast in two times. In the first layer, the bottom plates, some webs and diaphragms of the upper beam are poured with the pouring height of about 3.30m~6.22m. For the second layer, only the remaining 3m height and 1.2m grooves on both sides are poured. The support only bears the first layer of concrete load with a pouring volume of about 1289m3 and a total weight of about 3351t. The east main tower body is provided with four horizontal braces. The position and structure of the horizontal braces and tower crane buttresses must be considered in combination with the structure type of the upper beam support to avoid layout conflicts. According to the experiences in the similar projects [5-7] and the characteristics of this project, three design schemes are determined.

2.1 Scheme Introduction

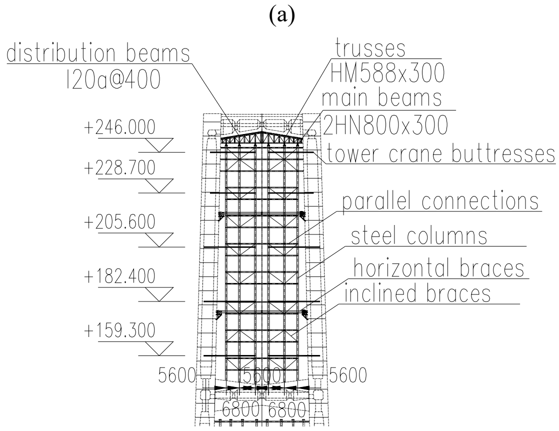
The upper beam support structure of Scheme I is mainly composed of support frames, corbels, main beams, trusses, coupling beams, unloading blocks, distribution beams, formworks, etc. The overall structure shows in Figure 3a. Three triangular brackets are symmetrically arranged along both sides of the bridge centerline to form the support platform with a spacing of 3.0m along the bridge. 2HN900× 300 steel is chose for support frames, corbels and coupling beams, the main beams are made of 2HN800 × 300 steel, trusses use HM588 × 300 steel, and the upper distribution beams are laid 20a I-beam according to the spacing of 0.4m. The triangular brackets are connected and fixed with the embedded anchor bars of the tower columns through the bolts at the corbels. The support is about 12m high, 12 embedded parts are set inside the tower bodies, and the total weight of the support is about 600t.
As shown in Figure 3b, the structure of Scheme II consists of steel columns, main beams, trusses, parallel connections, diagonal braces, unloading blocks, distribution beams, formworks, etc. About 20Φ800x10 columns are symmetrically organized along the center line of the bridge in 3 or 4 rows and 6 columns with a height of around 103m, 20 embedded parts of the buttresses are set inside the tower bodies, and the materials of other sections are the same as Scheme I. The total weight is nearly 950t.
The structure in Scheme III is made of steel columns, support frames, corbels, main beams, trusses, parallel connections, diagonal braces, unloading blocks, distribution beams, formworks, etc in Figure 3c. 12Φ800x10 steel columns about 103m high are symmetrically arrayed along the centerline in 3 rows and 4 columns with the same materials of other parts as Scheme I. The structure weighs approximately 950t.
The finite element software is used to model and analyze the three schemes, and the main calculations are shown in Table 1.

Table 1. The main results of design schemes for the upper beam

Design scheme	Vertical displacement (mm)	Shear forces at embedded parts (t)	Horizontal forces at embedded parts (t)
SchemeI	22	embedded parts above: 340 embedded parts below: 440	embedded parts above: 33(tension) embedded parts below: 370 (pressure)
SchemeII	40	Pressures from the steel columns: 250t	
Scheme III	33	embedded parts above: 110 embedded parts below: 265	embedded parts above: 150 (tension) embedded parts below: 270 (pressure)



(a)



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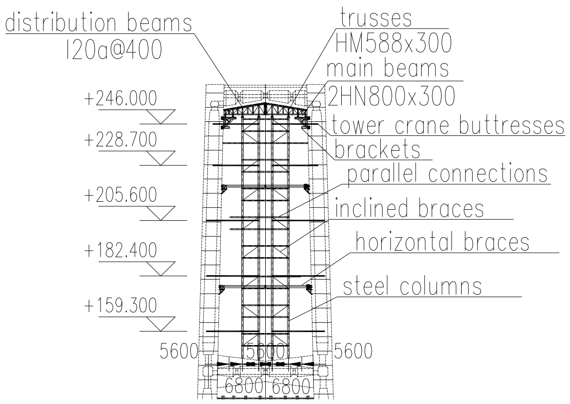

(c)

Figure 3. (a) The elevation of Scheme I (unit: mm), (b) The elevation of Scheme Ⅱ (unit: mm), (c) The elevation of Scheme Ⅲ (unit: mm)

2.2 Scheme Comparisons

The advantages for Scheme I are strong lateral wind resistance, small vertical deformation and low construction cost, while the disadvantages are that the embedded parts of the corbels under the support frame bear too much loads and the weight shared by the support frames on both sides is too large. In addition, it makes the construction difficult and risky, and conflicts with the buttresses of the tower crane.

For the second scheme, the strong point is that it avoids collision with the tower crane buttresses, meanwhile, it can support the horizontal bracing vertically. The weak points are that the column buttresses bear large stress, maximum vertical deformation, superelevation of support, poor lateral wind resistant ability, and high risk of instability under the influence of wind load.

In Scheme III, the good aspects are that the construction and installation are slightly less difficult, at the same time, the bracket can be reused. However, the vertical stiffness between the brackets and the steel columns is greatly different, leading to the uncoordinated vertical deformation. Apart from that, the loads borne by the brackets and the embedded parts at the lower corbel are large, while the bending stress of the truss' lower chord and the vertical bar at the bracket end exceeds the limit stress. Also like Scheme I, the small brackets of the upper beam support collide with the tower crane buttresses.

It can be seen that for the floor-type steel tube brackets such as Scheme II and Scheme III, the height of the steel column is over 100m, and the support is greatly deformed due to the wind load, temperature change and other factors, which will affect the quality of concrete pouring. Meantime the support needs to be connected with the tower columns by setting up buttresses from bottom to top. The space occupied by the support is large, which will affect the layout of the tower crane, tower crane buttresses and other structures. The support weighs heavily and costs much. For Scheme I, it can ensure the quality of concrete pouring for the upper crossbeam, and the area required for the support is also small. The total weight of the support is smaller than that of the steel tube structure, which reduces the steel cost. For the problems existing in the structure, the support can be planned as a parallel arch bracket, besides, brackets and embedded parts can be added to improve resistance at the corbels' embedded parts. Apart from that, the structure could be optimized by strengthening the local position of the truss vertical bar and adjusting the position of the tower crane buttresses to avoid conflicts with the layout. Considering the difficulty of construction, the bracket itself and the bracket embedded parts shall be designed separately, and their angle and position should be arranged during construction before welding to provide the convenience for construction. Scheme I was finally applied to site construction as shown in the figure below.

Figure 4. The construction situation on the spot

3. Conclusions and Suggestions

By comparing the design schemes of three conventional upper beams, the bracket method in the cast-in-place construction is finally determined for the upper beams at the east cable tower of Lingdingyang Bridge on Shenzhen-Zhongyang Link. The design scheme of cast-in-place beam with bracket method provides a reference for the design of the super-height, large-weight and long-span crossbeams at cable tower in complex marine environment, and brings some experience for the construction of cross sea bridges in domestic projects.

(1) The upper arch support can avoid the problem that the structural deformation of the floor-type steel tube bracket is large due to the influence of factors such as wind load and temperature change, which impacts on the concrete pouring quality of the upper beams. It can also optimize the structure, solving the problem of excessive stress on the embedded parts at the corbels and great construction difficulties. It has strong operability and saves costs effectively.

(2) During the construction process, the position and elevation of the buried parts of the brackets' embedded parts should be set accurately to meet the requirements of installation accuracy. All components shall be firmly connected by welding. At the same time, strengthening the on-site inspection and reinforcement work to ensure the safety of the upper beams during the whole construction process.

References

1. Song S Y, GuoJ, Su Q K, etal. Technical Challenges in the Construction of Bridge-Tunnel Sea-Crossing Projects in China[J]. Journal of Zhejiang University Science A: Applied Physics & Engineering , 2020, 21(7): 509-513.
2. XU Guoping, HUANG Qingfei. General Design of Shenzhen-Zhongshan River-crossing Link Project[J]. Tunnel Construction, 2018, 38(04): 627-637.
3. SONG Shenyou, CHEN Weile, JIN Wenliang, et al. Key technologies and challenges of Shenzhong Link[J]. Tunnel Construction, 2020, 40(1):143.
4. Yan Liyuan. Comparison and Choice of the Design Schemes for Brackets at the Top of the Cable Towers of the Self-Anchored Suspension Bridge. Traffic Engineering and Technology for National Defence, 2012, 10(03): 18-20+10.
5. LI Lu-ping. Design and Construction Technology of the Bracket Support of Entablature of the Tower. Value Engineering 2016, 35(16): 98-101.
6. ZHU Peng, ZHOU Xudong. Comparion and Analysis on Falsework Scheme for Upper Cross Beam of Main Tower of Dasha Channel Bridge of the Second Humen Bridge. Guangdong Highway Communications. 2018,44(04): 83-86.
7. Fu Wenxuan, YuanCan, ZhangKe, LiuGe, Huang Xiuping. Key Technology of Design and Construction of Cross-beam Supports for Main Tower of Wufengshan Yangtze River Bridge. Construction Techonology, 2022, 51(06): 19-23+35.