Study on force of steel bracket for construction of large span and wide steel box girder

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Abstract. Dongping waterway bridge is a steel concrete composite single-tower cable stayed bridge with spans of 35+260+50+64+66 m. The bridge M21-M31 beam section is constructed by steel pipe bracket. The steel pipe column is designed for transverse bridge to 2 groups of 4 rows, each 2 rows connected into a group, and the steel pipe column is connected through the profile steel connection system. The top of steel pipe column is equipped with profiled steel beam, the profiled steel distribution beam is equipped with Bailey beam and I-beam, and the longitudinal moving push-up slideway of the steel box beam is installed on the I-beam. In order to check the safety of steel pipe bracket in construction stage, the finite element model of steel pipe bracket and the field measured steel pipe stress are established by MIDAS software. The results show that the force and alignment change of the steel bracket construction used in this bridge is reasonable. In addition, through the finite element optimization of the existing bracket, it is proved that the optimized steel bracket structure can save 20% steel consumption under the premise of ensuring safety, which provides a reference for similar projects.

1. General Descriptions of project

The main bridge project of Dongping Waterway Super Bridge is the control project of the urban public transportation system test section of Nanhai District, Foshan City, Guangdong Province. The bridge adopts 35+260+50+64+66 m steel-concrete composite single-tower cable-stayed bridge type scheme, a-type pylon, pylon height 146.8 m, bridge deck width 46.5 m, bridge length 475 m, side pier and the auxiliary pier are provided with support. And the main span and 35m side span girder of small mileage side adopt steel box girder, and the other main beams adopt prestressed concrete box girder.

The main girder is a separated flat steel box girder with good wind resistance, strong integrity and graceful lines. The separation steel box is connected by a densely distributed I-beam, and the orthotropic steel bridge deck is arranged on the crossbeam, with a beam spacing of 3.0m. The height of the web in the steel box girder is 3.3m (inner contour), the bridge deck is 46.5m wide, the box width is 39.64m, the bridge deck has a 2% bidirectional cross slope, the ratio of height to width is 1:12.01 and the ratio of height to span is 1:78.79. A 2.5m wide pedestrian passage outside the steel box girder is set up, and the width of the wind fairing is 0.67m. The standard section of the steel box girder is 16mm thick, the bottom plate is 14mm thick, and the top and bottom plate are thickened to 22mm near the support. U-shaped rib plate is set on the deck-plate, and plate-shaped diaphragm is set along the
length direction of the bridge. The spacing is 3.0 m, the plate thickness is 10 mm, and diaphragm thickness is 14 mm at the cable. The diaphragm thickness at the support is adjusted according to the actual situation. The steel box girder of the whole bridge is divided into 31 sections, numbering in sequence JH, M1–M31. It can be divided into pier top beam section, no cable section beam section, standard section and closure section. The length of standard beam is 9m and the closure section length is 4.2m. The inside of the main bridge is shown in Figure 1. The standard cross-section of the main beam steel box girth is shown in Figure 2 [1].

![Figure 1. Elevation of Dongping Waterway Bridge (unit: cm)](image1)

2. **Bracket design scheme**

Steel girder is provided with two sections of steel box girder brackets, which are located on the east and west sides of the main bridge. The steel box girder bracket of the Pingzhou bank starts from the DP1# pier and passes through the DP2# pier and then crosses the left bank embankment to the water. It is mainly used for erecting M31 to M21 beam section longitudinal movement, installation support or temporary storage.

The total length of the Pingzhou bank bracket is 94.31m, of which the length of the support in the river is 39m, and the support is about 20m above the ground. There are four types of bracket foundation design. The first type is a cement mixing pile foundation with a diameter of 500 mm and the pile spacing of 400 mm. The pile foundation is paved with 20 cm thick sand mattress layer on top of which is reinforced concrete enlarged foundation. There are 2 caps on the riverside slope with the size of 2.3×4.6×0.8 m. There are 2 caps on the backwater slope with the size of 4.6×4.6×0.8 m. It is suitable for the bracket foundation of the river embankment section. The second type is Φ400mm PHC pipe pile foundation. The length of PHC pipe pile is about 23 m and the top of the pile is a reinforced concrete cap with the size of 100×100×80cm. It is suitable for shore bracket foundation. The third type is a Φ630×6mm (820×8mm) steel pipe pile foundation, on which the bracket is directly mounted for use in the underwater bracket foundation. The fourth type is to install pre-embedded parts on the top of
the pier cap to connect steel pipe column. The Steel pipe column is designed for transverse bridge to 2
groups of 4 rows, each 2 rows connected into a group, and the steel pipe column is connected through
the profile steel connection system. Steel pipe column top set 2H588x300x20x12mm profiled steel
distribution girder. The top of steel pipe column is equipped with profiled steel beam, the profiled steel
distribution beam is equipped with bailey beam and I-beam, and the longitudinal moving push-up
sideway of the steel box beam is installed on the I-beam. The bracket layout is shown in Figure 3
[2-4].

3. Finite element model calculation of steel pipe support

3.1. Force analysis of steel pipe support

3.1.1. Force calculation of steel pipe support. Aiming at the force condition of the bracket in the side
span closure section, the steel pipe support member system model is established by using the finite
element software of Midas bridge structure, and the beam element is used in the steel bracket. In the
finite element calculation, according to the structural characteristics of the steel bracket, two finite
element models of the bracket are established with DP2 pier as the boundary, and the bracket 1 and the
bracket 2 are named respectively. The bracket 1 model has 3649 nodes, 7316 elements, and the
bracket 2 model has 7229 nodes, 12306 elements. The bottom of the steel pipe bracket adopts a fixed
constraint, and the weight of the steel box girder carried by the steel bracket is evenly distributed on
the bailey beams on both sides. According to the finite element calculation and the measured force
situation of the steel pipe bracket, the steel pipe bracket 2 is optimized based on the purpose of
material saving. After optimization, there are 7291 nodes and 12374 elements in the model [5、6]. It
can save about 20% steel pipe pile. Considering the self-weight of the steel pipe bracket, the
self-weight of the bailey beam, the weight of the steel box girder and the wind load, the force of the
steel pipe bracket is shown in Figure 4-6.
Figure 4. Analysis and calculation of bracket 1

Figure 5. Analysis and calculation of bracket 2
Figure 6. Analysis and calculation after optimization of bracket 2

It can be seen from Fig. 4-6 that the maximum stress of the bracket 1 and the bracket 2 can be obtained by establishing finite element model and considering the self-weight of the steel bracket, the weight of the steel box girder and the wind load. And the maximum stress of the bracket 1 and the bracket 2 are 198.2Mpa and 195.5Mpa respectively, which are the local position of the bracket and bailey beam connection. It is suggested to reinforce this position in similar projects to ensure the safety and reliability of the structure, while the stress of steel pipe bracket is in a small range, so the number of steel pipe bracket can be reduced and the optimal layout can be considered. Based on the purpose of saving material, the bracket 2 is optimized (Figure. 6), and some steel pipe brackets are reduced, and the second and fifth row of steel pipe piles are changed from double row to single row (from left to right). After optimization, the maximum stress is 195.6Mpa, which is also located at the position where the bracket is connected with the bailey beam. The stress of the steel tube bracket is still in a small range. Before and after optimization, the force change of the bracket and the Bailey frame is less, but the material of the optimized bracket can save nearly 20%, which can save the project cost greatly and the optimized design calculation can be carried out.

3.1.2. Stress test of steel tube bracket. In order to further analyse the force of the steel bracket, a sensor is installed on the bracket. The stress variation of the steel bracket during the erection of the steel box girder is tested, and the stress variation of the steel bracket during the construction process is analysed by experiment.

| Position | Initial reading (με) | Stress of working condition 1 | Stress of working condition 2 | Stress of working condition 3 |
|----------|---------------------|------------------------------|------------------------------|------------------------------|
| middle and lower of DP1# | 2822 | -24.42 | -5.02 | -0.71 |
| upper middle of DP1# | 3084 | -51.41 | -15.74 | -0.08 |
| lower position of DP1# | 2531 | -46.07 | -15.51 | -0.49 |
| upper middle of DP2# | 2726 | -79.20 | -9.75 | -1.02 |
| Lower position of the river | 2102 | -71.38 | -30.54 | -1.26 |
| lower position of DP1# | 3653 | -32.71 | -26.10 | -0.53 |
| middle and lower of DP2# | 6767 | -102.33 | -11.74 | -1.18 |
| upper position of the river | 2476 | -33.80 | -29.67 | -1.07 |
Description: Working condition 1 is the completion of the laying of the steel box girder; working condition 2 is before the dismantling of the bracket after the closure; Working condition 3 is after the dismantling of the bracket.

It can be seen from Table 1 that in the process of laying steel box girder, the steel pipe bracket is under reasonable force, the stress increment is in a lower range, and the maximum stress increment is 102.33Mpa. Within the allowable range of design, and after the unloading of steel box girder laid, the stress of steel pipe bracket basically restored to the initial state, indicating that its stress state is good, laying the foundation for further optimization design. The results of optimization design can be seen in the finite element calculation. However, from the measured results of the bracket stress, there is a phenomenon of uneven force on the bracket during the construction process, which may be caused by uneven settlement of the foundation or uneven load.

3.2. Stability calculation of steel pipe bracket

![Figure 7. Stability analysis of bracket 1 (stability factor: 3.795)](image)

![Figure 8. Stability analysis of bracket 2 (stability factor: 4.341)](image)
Figure 9. Stability analysis of bracket 2 after optimization (stability factor: 4.214)

It can be seen from Figure 7-9 that the stability coefficients of the 1 and 2 brackets are relatively large, 3.131 and 3.148 respectively, which all meet the stability requirements and have a certain stability reserve. The stability coefficient of bracket 2 after optimization is 3.096, which is 1.65% lower than that before the optimization, and can be neglected. It is indicating that the optimization design has little effect on the stability. The amount of steel used in the steel bracket can be saved by 20% by adopting the optimized design, but the stability of the steel bracket has little change, which can ensure the stability requirements of the steel bracket and achieve the purpose of saving steel. The optimized design adopted is reasonable.

4. Conclusion
The steel box girder of Pingzhou bank of Dongping Waterway Bridge is constructed by using the brackets. Through finite element analysis and field measurement of stress variation of steel brackets, the results are in a reasonable range. The construction section of the bracket was completed in January 2017. It has been proved that the construction of the bridge adopts steel brackets and the deformation and linear shape are reasonable. In addition, through the finite element optimization of the existing bracket, it is proved that the optimized steel bracket structure can save 20% steel consumption under the premise of ensuring safety, which provides a reference for similar projects.

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References
[1] Shang Zhang, Wei Su, Chunyan Yin, Yuewu Zhou, Design and Research of Steel Box Girder in Dongping Waterway Cable Stayed Bridge, RAILWAY STANDARD DESIGN. 59 (2015) 78-81.
[2] Anrong Gao, Jianjun Zhang, Song Li, et al, Design and Construction of Scaffolding for Cast-in-Situ Concreting of Very Wide Box Girders of Edong Changjiang River Bridge, Bridge Construction. S1 (2009):23-26.
[3] Huaiyu Yang, Side Span Scaffold Construction Technology Research of Long-span Composite Beam Cable-stayed Bridge, RAILWAY CONSTRUCTION TECHNOLOGY. 6(2017);56-58
[4] Jilian Wang, Kaiqiao Chen, Weiqi Mao, Design of scaffolding for Cast-in-Situ Segment of Main Span of Wuhan Avenue Cable-Stayed Bridge Spanning Railway, Bridge Construction. 43(2013)103-108.
[5] Chuanxi Li, Wei Song, Chaoyun Luo, Yuping Zhang, Method for Erecting the Side Span Steel Box Girder of Cable-stayed Bridge of Jiashao Bridge and Stress Analysis of Support. Journal of China & Foreign Highway. 32(2012);129-133.