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Optimization analysis of external prestressing reinforcement scheme for concrete curved girder bridge

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Abstract. In this paper, the external prestressing method is used to reinforce a prestressed concrete curved girder bridge. The calculation and analysis model of external prestressing reinforcement is established. The alignment of external prestressing tendons and the tension control stress are studied. The reasonable alignment of external prestressing tendons and the parameters of tension control stress are given. The results show that when two steering blocks are set at one-fourth span and three-quarters span to control the alignment and the prestress value outside the curved girder bridge is 25%-35% larger than that inside the bridge, not only the bearing capacity and stiffness requirements can be met, but also the torque produced by the main girder under the external load can be effectively reduced.

1. Introduction

The curved girder bridges are characterized by complicated forces, bending-torsion coupling and repeated traffic loads. After many years of operation, most of the curved girder bridges suffer from such diseases as support void, beam cracking and beam deflection. The serious can lead to some overturn engineering accidents, resulting in property losses and casualties. Referring to the relevant literature, it is found that domestic scholars have done more research on the overturning of single column pier [1-4]. The method of adding additional cover beams, adding supporting pier columns and transversal limit is used to add external components. Although the reinforcement effect is good, the applicability is not strong. Chunfu Jin and Like Tang have studied the reinforcement of concrete curved girder bridges by external prestressing, and they have achieved some results. But their research is not enough, especially for the linear arrangement of external prestressing tendons and the control parameters of tension [5-6].

2. General situation of reinforcement engineering

A prestressed concrete curved continuous girder bridge with a span of 4 x 25m is a double chamber box girder of equal section. The beam is 160cm in height, 1235 cm in roof width, 785 cm in floor width, 225 cm in wing cantilever length, 40 cm in midspan web thickness and 30 cm in roof and floor thickness. The main girder adopts C50 concrete and the prestressed reinforcement adopts 1860MPa stranded wire. The substructure is 1~5 pier from left to right. In this paper, MIDAS/Civil software is used to establish the spatial grillage analysis model for calculation, as shown in Figure 2-1.

The bridge diseases are as follows:

- (1) There are many contraction cracks in the box girder, and the main girder is deflecting.



- (2) There are some honeycomb hemp and stress cracks on the web and floor of the box girder.

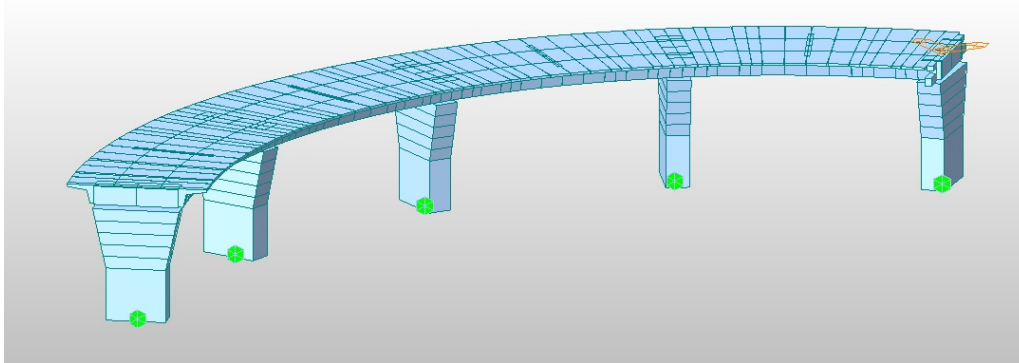


Figure 2-1. Finite element numerical analysis model

3. Damage simulation

Referring to the previous literature[7], it is found that the simulation of damage state of bridge structure is mainly realized by the reduction of beam stiffness and longitudinal prestress. The deflection fitting method is used to determine the damage simulation scheme. Take the fourth span as the research object.

Table 1. Damage calculation model

Computational model	Working condition number	State description
Not considering damage	1	Original design state, no prestress reduction
Fourth span 0.3L to 0.7L section stiffness loss 15%	2	Longitudinal prestress reduction 15%
	3	Longitudinal prestress reduction 20%
Fourth span 0.3L to 0.7L section stiffness loss 20%	4	Longitudinal prestress reduction 15%
	5	Longitudinal prestress reduction 20%

The results are shown in table 2.

Table 2. The deflection of the control section of the fourth span girder in calculation conditions (unit: mm)

Control section	L/8	L/4	3L/8	L/2	5L/8	3L/4	7L/8
Working condition 1	13.04	19.31	24.50	30.01	25.63	20.37	13.91
Working condition 2	16.91	25.05	31.77	38.92	33.24	26.41	18.04
Working condition 3	17.61	26.09	33.09	40.54	34.62	27.51	18.79
Working condition 4	18.99	28.12	35.67	43.70	37.32	29.66	20.25
Working condition 5	19.52	28.92	36.67	44.93	38.37	30.49	20.82

The average deflection of the fourth span is 46 mm, the average deflection of L/4 is 29 mm and the average deflection of 3L/4 is 30 mm. Comparing and analyzing, the ultimate reinforcement calculation model is that the stiffness of part section is reduced by 20%, and the longitudinal prestress is reduced by 20%.

4. Alignment optimization of externally prestressed tendons

For continuous girder bridges, prestressing tendons achieve vertical bending by setting steering blocks. In order to control the alignment of external prestressing tendons rationally, the influence of external prestressing on the main girder's stress characteristics is compared when one steering block, two steering blocks and three steering blocks are set in each span. Under three different conditions, the length, area and tension control stress of external prestressing tendons are identical. See Figure 4-1 to Figure 4-4.

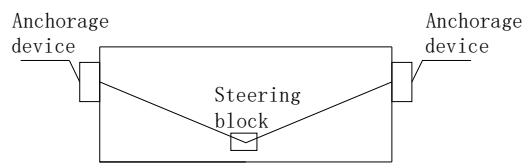


Figure 4-1. Set one steering block

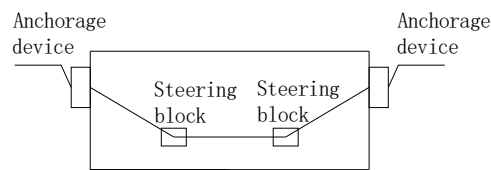


Figure 4-2. Set two steering block

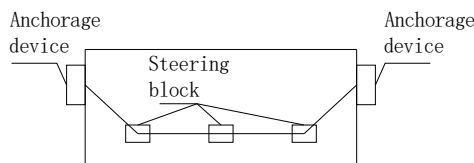


Figure 4-3. Set three steering block

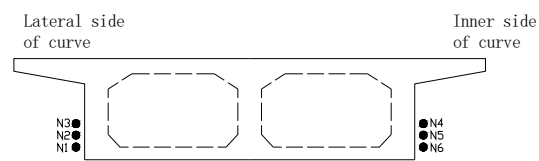


Figure 4-4. Transverse layout of external prestressed steel bundles in the midspan

The longitudinal bending moments of the girder under external prestressing are calculated according to the alignment of external prestressing tendons controlled by different steering blocks. The results are shown in Figure 4-5 to Figure 4-6.

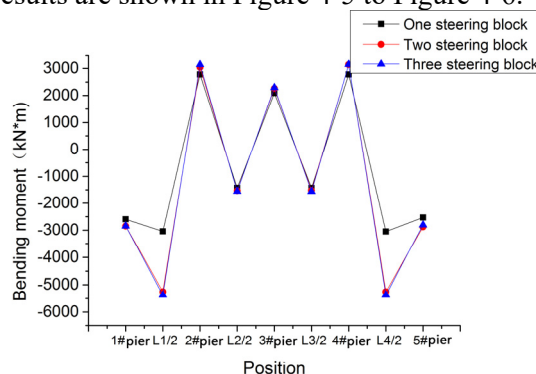


Figure 4-5 The main section bending moment of main girder when set with different steering blocks

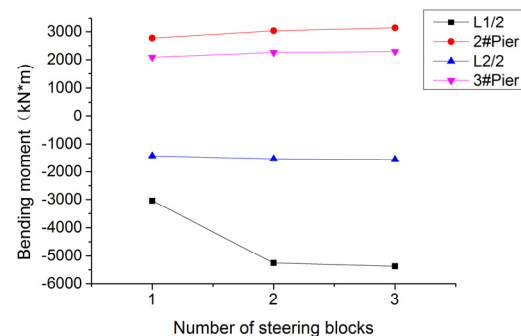


Figure 4-6 The main section bending moment changes when setting up different number of steering blocks

The results show that when two steering blocks are set, relative to setting a steering block, the maximum increment of bending moment of the main beam under external prestressing is 72.41%, while when three steering blocks are set relative to two steering blocks, the maximum increment of bending moment of the main beam under external prestressing is only 3.44%. There are two steering blocks in each span of 1/4 span and 3/4 span.

5. Stress optimization for tension control of externally prestressed tendons

Based on the above analysis, we use two steering blocks to control the alignment. However, due to the existence of the curvature radius of the curved beam, external prestressing will produce a horizontal radial force, which may produce unfavorable torque to the main beam. In order to study whether the unequal arrangement of external prestressing on both sides of the curve or the different tension control stress can help to adjust the torsion of the main beam, the following conditions are set for calculation (Table 3).

Table 3. Tensioning condition of external prestressing

Number of working	State description
-------------------	-------------------

conditions	
1	Tension of internal and external prestressing tendons
2	The tension control stress of the inner prestressing tendons is 1376MPa, and the tension stress of the outer prestressing tendons is 70% of the inner side.
3	The tension stress of the external prestressing tendons is 1376MPa, and the tension stress of the inner prestressing tendons is 70% of the inner side.

$$(\text{Reduction rate} = \frac{(\text{Torque without external prestressing} - \text{Torque under external prestressing conditions})}{\text{Torque without external prestressing}} \times 100\%.)$$

The results (Figure 5-1) show that the external prestressing force can resist the torsion of the girder caused by some external factors. When the tension control stress of external prestressed tendons is larger than that of internal prestressed tendons, the torsion reduction effect of external prestressed tendons on the main girder is obvious. Compared with no external prestress, the maximum reduction rate reaches 27.63%; the maximum reduction rate of external prestressing tendons is 9.50%. The tension of the inner prestressing tendons will increase the torque by 22.44% when the stress is greater than the outside.

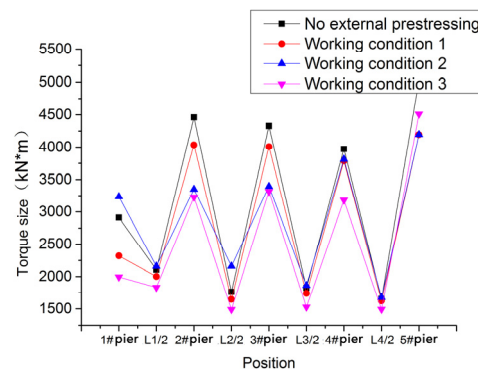


Figure 5-1 Torsion under short term combination under different tension conditions

In order to determine that the external prestressing tendons of curved girder have more control stress than the internal prestressing tendons, the external prestressing tendons have better effect on reducing the torque of the main girder of curved girder bridge under the external action. The following gradient conditions are set up: the external prestressing tendons tensioning control stress is 1376MPa, and the internal prestressing tendons tensioning control stress. In turn, 15%, 20%, 25%, 30%, 35%, 40% were reduced to 1 from working condition 6.

The results show (Figure 5-2 to Figure 5-3) that when the tension control stress of external prestressing tendons on the outside of the curve is greater than that of external prestressing tendons on the inside of the curve, the torque value of the main beam decreases and the external prestressing force decreases with the increase of the difference of tension control stress between the inside and outside of the curve. The torsion control effect of the main girder is better. As shown in Figure 4-9, the larger the slope of the curve is, the higher the torque reduction efficiency of external prestressing on the main girder will be.

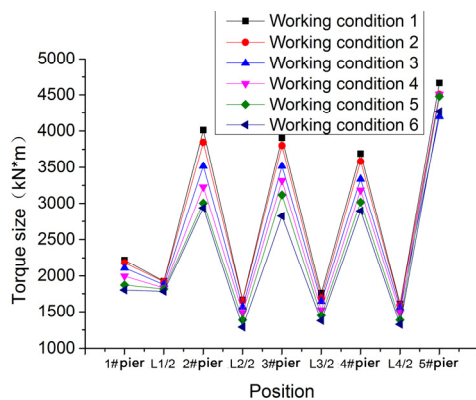


Figure 5-2 Torsion under short term combination under different tension conditions

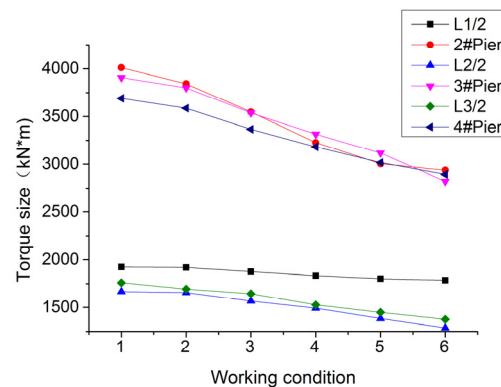


Figure 5-3 Torsion of different section under short term combination under different tension conditions

In order to determine the optimum difference of tension control stress of external prestressed tendons on both sides of the curve, the influence of external prestressing on other indexes of the main girder should also be considered.

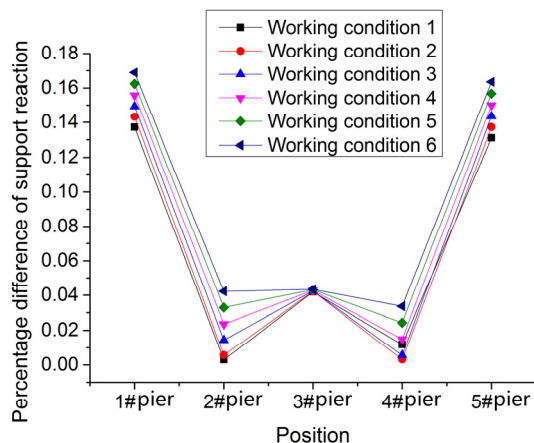


Figure 5-4 Torsion under short term combination under different tension conditions

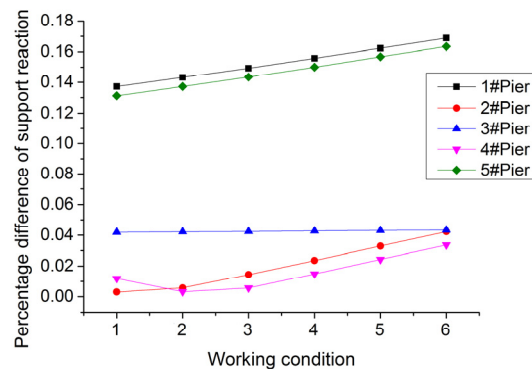


Figure 5-5 Torsion of different section under short term combination under different tension conditions

The results show that (Figure 5-3 to Figure 5-4) the greater the difference of tension control stress between the inside and outside of the curve, the greater the difference of reaction between the inside and outside of the support at each pier column, the more uneven the bearing force, the easier the bearing disease, but the change is gentle and the slope is small.

Based on the above analysis, the external prestressing can effectively reduce the torque of the main girder under the external factors when the external prestressing control stress of the external prestressing tendon outside the curve is 30% greater than that of the external prestressing tendon inside the curve. It is suggested that the difference of tension control stress between inside and outside of curved girder bridge should be calculated at 25%-35% to determine the optimal difference.

6. Conclusion

1. Setting two steering blocks at one-fourth span and three-quarters span can effectively improve the bearing capacity. Compared with setting one steering block, the maximum increase of bending moment of the main beam under external prestressing can reach 72.41%, and the efficiency of external prestressing can be significantly improved; while setting three steering blocks is relative to setting two steering blocks, the maximum increment of bending moment of the main beam under external prestressing is only 3.44%. Adding more steering blocks will not increase the efficiency of external

prestressing. It is suggested that the reasonable number of steering blocks should be determined by considering the efficiency and economy of prestressing.

2. When the tension control stress of the external prestressing tendons is 30% greater than that of the internal prestressing tendons, the maximum reduction rate of the external prestressing tendons is 27.63% compared with that of the external prestressing tendons; when the internal and external prestressing tendons are iso-tensioned, the maximum reduction rate of the external prestressing tendons is 27.63%. Only 9.50%; when the tension control stress of the inner prestressed tendon is 30% greater than that of the outer prestressed tendon, the maximum torque will be increased by 22.44%. It is suggested that the tension control of the lateral prestressing tendons should be 25% to 35% larger than the inner side.

Acknowledgments

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