Figure 2: The construction sequence of original design

Since the influence of local electric tower transferring during the construction the 1st and the 2nd separation does not have the construction conditions, to ensure the entire project duration, the 3rd separation structure should be conducted first, so to adjust the tendon tensioning pattern accordingly. The comparative analysis of the 3rd separation bridge which with two different tendon designs: one is before adjustment; another is after adjustment with above pattern will be conducted in the following content.

2.1 Establishment of finite element model

The finite element analysis model of a continuous girder (5×25) will be built by the bridge professional computer program Dr. Bridge V3.03. Two cases with the same tendon line type and the equal material consumption of tendon will be considered: one is single end tensioning span by span, another is simultaneous tensioning at both ends of the whole continuous structure. The whole bridge is divided into 93 nodes and 92 units. The finite element model of the whole structure is shown in figure 3.

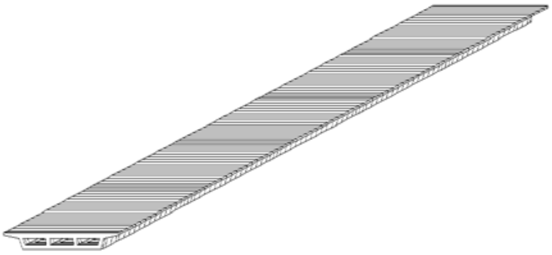

Figure 3: The finite element analysis model of the bridge

In Dr. Bridge program V3.03, the load case can be directly input in accordance with the design: highway -I load. The influence on continuous box girder mechanic performance can be reflected through the loading transverse distribution coefficient, lane reduction coefficient and eccentric load coefficient etc.

According to the result of dynamic analysis with the finite element model, the fundamental frequency is 2.281. According to the formula (4.3.2) in design code, the impact coefficient of the bridge is 0.13:

$$\mu = 0.1767 \times \ln(2.281) - 0.0157 = 0.1300 \quad (1)$$

The data of loading transverse distribution coefficient is shown as the following:

$$1.15 \times 4 \times 0.67 = 3.082 \quad (2)$$

Among formula (2), 1.15 are empirical eccentric load factor, 4 is lane number, 0.67 is lane reduction factor [2].

3. THE INFLUENCE ANALYSIS OF THE BRIDGE CAUSED BY THE CHANGE OF TENDON TENSION PATTERN

3.1 Summary

In theory the influence to support cast in place prestressed concrete continuous box girder caused by the change of tendon tension pattern is mainly embodied in the pre-stress loss [5,6]. Since the different length of tendon, the pre-stress loss in the whole bridge both ends tension at the same time will bigger than that of single end tension with span by span usually. So, the efficient pre-stress in the former will be smaller relevantly. The calculation results show that, although the effective pre-stress of the structure is reduced after adjusting the tensioning pattern, the checking computations of the structure still meet the requirements of the code.

Based on the result of the two-tendon arrangement case above, the compared analysis will be made in the following.

3.2 Comparative Analysis of the Results of Crack Checking in Normal Service Limit State in Persistent Condition

According to the provisions of article 6.3 in code about lasting condition normal service limit state checking calculation, the related stress result of the two-tensioning mode can be obtained directly by Dr. Bridge program [2]. The minimum normal stress is shown in Figure 3, Figure 4, Table 1 and Table 2, and the maximum principal tensile stress of the section is shown in Figure 5 and Table 3.

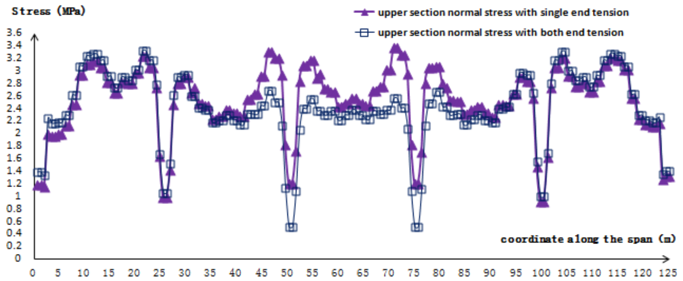

Figure 4: Normal stress result in each section upper edge

Table 1: Normal stress result in each section upper edge (MPa)

Key Section	Sectional Tension	Disposable Tension	Stress Difference
1st mid-span	3.1	3.23	-0.13
2nd support	0.969	1.05	-0.08
2nd mid-span	2.28	2.21	0.07
3rd support	1.19	0.505	**0.69**
3rd mid-span	2.56	2.37	0.19
4th support	1.19	0.504	**0.69**
4th mid-span	2.43	2.29	0.14
5th support	0.906	0.989	-0.08
5th mid-span	3.19	3.27	-0.08

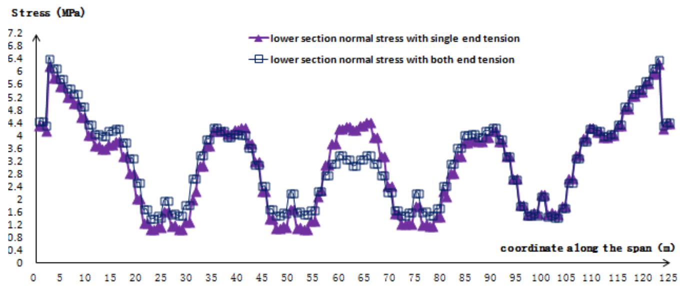

Figure 5: Normal stress result in each section lower edge

According to the results of Figure 3 and Table 1, there is no tensile stress at the upper edge of two tension cases. In the range of the second to the fourth span, the normal stress of the case which is with single end tension is slightly larger than that of tension at both ends, the biggest difference occurs in the middle support section (0.69MPa). The situation of other position is just the opposite.

According to the results of Figure 4 and Table 2, there is no tensile stress at the lower edge of two tension cases. In the section of the mid-span of the 2nd and the 3rd, the 5th support point, the normal stress of the case which is with single end tension is slightly larger than that of tension at both ends, (the biggest difference is 1.1MPa). The situation of other position is just the opposite.

Table 2: normal stress result in each section lower edge (MPa)

Key section	Sectional tension	Disposable tension	Stress difference
1st mid-span	4.01	4.36	-0.35
2nd support	1.63	1.96	-0.33
2nd mid-span	4.16	4.14	0.02
3rd support	1.69	2.18	-0.49
3rd mid-span	4.18	3.06	**1.12**
4th support	1.79	2.18	-0.39
4th mid-span	3.8	3.96	-0.16
5th support	2.16	2.08	0.08
5th mid-span	4.01	4.06	-0.05

According to the results of Figure 5 and Table 3, the first principal stress result of each section in two tension cases does not exceed the limit of the code (-1.33MPa). There is almost no different in two tensile modes.

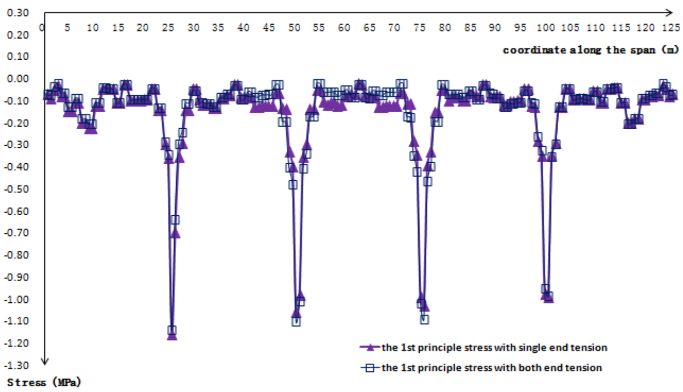

Figure 6: The 1st principle stress result in each section

According to the stress calculation of the prestressed concrete flexural members in persistent condition of the code, the related result can be read directly from the bridge Dr. V3.03. The maximum of the normal stress of concrete is shown as Table 4 and Table 5, the maximum of the 3rd principal stress is shown as Table 4.

Table 3: the 1st principle stress result in each section (MPa)

Key Section	Sectional Tension	Disposable Tension	Stress Difference
1st mid-span	-0.12	-0.11	-0.01
2nd support	-0.70	-0.64	-0.06
2nd mid-span	-0.07	-0.07	-0.01
3rd support	-0.98	-1.01	0.03
3rd mid-span	-0.03	-0.03	0.00
4th support	-0.99	-1.02	0.03
4th mid-span	-0.03	-0.03	0.00
5th support	-0.99	-0.98	-0.01
5th mid-span	-0.04	-0.04	0.00

3.3 Comparative Analysis of Compressive Stress of Concrete Normal Section in Persistent Condition Service Stage

According to the results of Table 4 and 5, the maximum of the compressive stress of concrete in all sections of the structure with two tendon tension cases meet with the corresponding requirement of code (meaning that less than 16.2MPa of C50 concrete). Among them the biggest difference is 0.74MPa in 4th supported section upper edge and 1.04MPa in 3rd mid-span in lower edge.

Table 4: Normal stress of concrete in each section upper edge (MPa)

Key section	Sectional tension	Disposable tension	Stress Difference
1st mid-span	10.3	10.5	-0.2
2nd support	8.58	8.66	-0.08
2nd mid-span	10.2	10.2	0
3rd support	9.16	8.48	**0.68**
3rd mid-span	10.2	10.1	0.1
4th support	9.18	8.44	**0.74**
4th mid-span	10.4	10.3	0.1
5th support	8.52	8.6	-0.08
5th mid-span	10.4	10.5	-0.1

According to the results of Table 4, the third principal stress result of each section in two tension cases does not exceed the maximum limit value of the code:19.44MPa (C50 concrete). Among them the biggest difference is 0.69MPa in 4th supported section.

Table 5: Normal stress of concrete in each section lower edge (MPa)

Key section	Sectional tension	Disposable tension	Stress difference
1st mid-span	6.35	6.7	-0.35
2nd support	5.89	6.22	-0.33
2nd mid-span	8.02	8	0.02
3rd support	4.74	5.19	-0.45
3rd mid-span	7.77	6.73	**1.04**
4th support	4.82	5.18	-0.36
4th mid-span	7.58	7.74	-0.16
5th support	6.43	6.35	0.08
5th mid-span	6.64	6.7	-0.06

Table 6: the 3rd principle stress result in each section (MPa)

Key section	Sectional tension	Disposable tension	Stress difference
1st mid-span	10.69	10.74	-0.05
2nd support	8.57	8.66	-0.09
2nd mid-span	10.35	10.26	0.09
3rd support	8.72	8.03	**0.69**
3rd mid-span	10.35	10.16	0.19
4th support	8.72	8.03	**0.69**
4th mid-span	10.4	10.27	0.13
5th support	8.51	8.6	-0.09
5th mid-span	10.67	10.74	-0.07

3.4 Comparative Analysis of Calculation Results of Prestress Losses

In order to understand the loss of restressing force, the calculation results under two tension mode are listed as shown in Table 6 and Table 7. According to the data in the Table 6 and Table 7, the prestressing loss rate of web tendon N1~N3 are about 29% to 34% when the tension is tensioned at both ends at the same time; While in single end span by span tension mode, the prestressing loss rate of the same tendons are about 19% to 24%, the difference of two mode mentioned above is 10%.

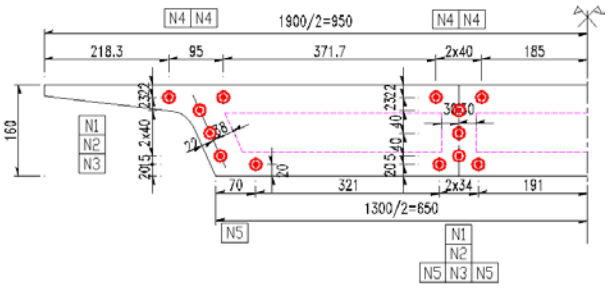

Figure 7: Sketch map of steel beam number (1/2 section, dimensioning unit: cm)

Table 7: Schedule of prestressing loss with single end span by span tension mode (MPa)

Position	Tendon Identifier	Control Stress	Permanent Stress	The Loss Rate
The first construction sections	N1	1358	1071	21.1%
	N2	1358	1070	21.2%
	N3	1358	1046	23.0%
The middle construction sections	N1	1358	1065	21.6%
	N2	1358	1106	18.6%
	N3	1358	1061	21.9%
The last construction sections	N1	1358	1014	25.3%
	N2	1358	1053	22.5%
	N3	1358	1028	24.3%
The whole bridge	N4	1285	1085	15.6%
	N5	1285	1091	15.1%

Note: N1~N3 is the web tendon (17 twisted steel strand of 15.2mm, N4, N5) for the long tendon roof and floor (with 10 steel strands of 15.2mm), as shown in figure 6.

Table 8: A list of prestressing losses at full tensioning at both ends tension mode (MPa)

Tendon Identifier	Control Stress	Permanent Stress	The Loss Rate
N1	1358	906	33.3%
N2	1358	958	29.5%
N3	1358	899	33.8%
N4	1285	1140	11.3%
N5	1285	1150	10.5%

For the long straight tendon in roof and floor of the box girder, the full combined disposable single end tension can be carried out only when the box girder has been completed (the stress loss rate is about 16%). Since the effective length of steel tension is larger, the stress loss is bigger than that of full tensioning at both ends, so as to compensate the stress loss of both ends tension mode.

4. CONCLUSIONS AND RECOMMENDATIONS

Through the comparative analysis with two different tensioning methods results by FEM, the conclusions and suggestions are as the following:

1. Since the prestress loss of cast-in-place segmental is slightly smaller than the whole bridge, the restressing effective ratio of single end tension is always larger than that of both ends tension.

2. It can't be qualitatively considered that the stress loss rate of single end tension span by span must be smaller than that of both ends tension, such as the long tendon in the roof and floor of the box girder in this paper. It must be illustrated with real result。

3. When conditions permit, single end tension span by span is strongly suggested in the normal prestressed concrete continuous box girder (such as 3~6 span), so as to improve the structure pre-stress and safety reserve.

4. When the condition constraint leads to adjust tendon tensioning mode, the discussion of the adjustment plan should be carried out on the premise of ensuring the safety of the structure, so as to avoid the low pre-stress and other adverse effects.

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