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Monitoring of External Prestressing Tendons Construction Process of Jiamusi Highway Prestressed Concrete Bridge during Strengthening in China

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Keywords: Jiamusi Bridge; External Tendon; Monitoring; Tensile Force; Crack; Elongation; Deformation

Abstract. Jiamusi highway prestressed concrete bridge is located in the Jiamusi City within Heilongjiang province in the east north of China. The strengthening and repairing of the bridge structure can be provided an effective and economic solution in appropriate situation. The objective of this study are to monitor the construction process of external prestressing tendons for strengthening of Jiamusi highway prestressed concrete bridge. Monitoring process includes measurement of external prestressing tendons natural frequency, monitoring of tensile forces values of external prestressing tendons, monitoring of development of anchor beams cracks, and monitoring of anchor beam deformation. The results of monitoring process show that the box girder No. 11 has the largest values of proportional coefficient (K) and the maximum value is 327.8. Box girder No. 8 has the largest values of frequency, the maximum value is 3.499. Five levels of tension are used in the application of tensile force in the tension process of external prestressing tendons. These levels are level 1=248.2kN, level 2=496.4kN, level 3=744.6kN, level 4=992.8kN, and level 5=1241kN. The measured tendons elongation values of left box girder No.8 are more than the theoretical values. For left and right box girder No. 9, side external tendons of left box No. 10, and left and right box girder No. 11, the measured values are less than theoretical values of elongation. After tension process, there are no new cracks in the top, web, and bottom of anchor beam and a small number of cracks developed slightly. These cracks are found around ducts of external tendons. The length of cracks rang from 0.03m to 0.5m and width rang from 0.05 mm and 0.25mm. The longitudinal deformation of the interface and top of anchor beam is very small, ranging from 0.001mm to0.115mm, which averaged 0.026mm. The overall state of anchor beams and box girders during strengthening is good.

Introduction

The strengthening of concrete structure involves upgrading of the strength and stiffness of a structure members, and the repair process involves re-establishing the strength and function of the damaged members. The prestressing systems can be defined as the preloading of a structure before the application of the service loads, and consist of two types of prestressing. The first type is known as pre-tension prestressing and the second type is known post-tension prestressing. Post-tensioning is a method of strengthening of concrete structure with high strength steel strand or bars referred to as tendons [1, 2].

External post-tensioning is defined as a system in which the pre-stressing tendons or bars are located outside the concrete section. The prestressing force is transferred to the member section through end anchorages, deviators or saddles. The use of external post-tensioning became popular in the last two decades, after the improvement for corrosion protection of external tendons by methods such as epoxy and grease coating. [3, 4].

The main aim of the bridge structure strengthening by using additional external prestressing tendons is to fulfill all necessary serviceability criteria and not to extend its ultimate limit state. The use of external post-tensioning for the strengthening of existing bridges has been used in many countries since the 1950s and has been found to provide an efficient and economic solution for a wide range of bridge types and conditions. Strengthening by using external post-tensioning is simply the application of an axial load combined with bending moment to improve the flexural and shear capacity of the bridge structural members. [5, 6]

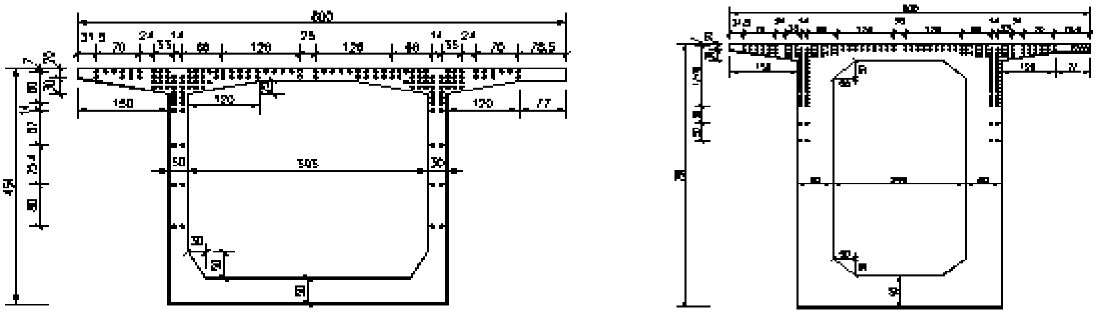
The objective of this study is to monitor the construction process of external prestressing tendons for strengthening of Jiamusi highway prestressed concrete bridge. Monitoring process includes measurement of external prestressing tendons frequency, monitoring of tensile forces values of external prestressing tendons, monitoring of development of anchor beams cracks, and monitoring of anchor beam deformation.

Description of Jiamusi Highway Prestressed Concrete Bridge

Jiamusi highway prestressed concrete bridge is located in the Jiamusi City within Heilongjiang province in the east north of China. The total length of the bridge is 1396.2 m and the width is 17 m. The bridge was open to traffic in September 1989. The type of the bridge is a continuous prestressed concrete T-shape rigid frame with hanging beams and simply supported T-beams. T-shape rigid frame structure consists of prestressed concrete box girders. Fig. 1 shows the layout of the bridge structure and Fig. 2 shows the pier and span prestressed box girder layout.

(a) (b)

Fig. 1 View of a bridge structure: (a) Spans of bridge view, (b) T-shape structure



(a) (b)

Fig. 2 Box girder layout: (a) Pier box girder, (b) Span box girder

Strengthening of the Bridge Using External Prestressing Tendons

The location of the bridge is important in Jiamusi City to develop the regional economy in the Heilongjiang province and it is always subjected to the heavy traffic load. According to the damages inspection by the team of inspection in School of Transportation Science and Engineering/ Bridge and Tunnel Engineering/ Harbin Institute of Technology (HIT), the corbel in the part of cantilever end suffers from down deflection. This deflection is about 10.3cm, and meanwhile, when the vehicles is passing on the bridge structure, the vibration of the bridge is large and the duration of vibration is long, which effects the safety and the normal using of the bridge structure. The effects of creep and shrinkage of concrete related to cause the deflection in bridge structure, resulting the losing in the stiffness, resistance, and prestress in the main girder. Therefore, there is a need to strengthen the bridge structure. The strengthening process includes two stages. The first stage is the laying of the leveling layer for bridge deck pavement, and the thickness of leveling layer range between 10cm in the part of corbel and zero in the part of pier. The second stage includes the strengthening of box girders by using external prestressing tendons. The design and construction of external prestressing system includes the design and construction of anchor beam which includes the design of re-bars and the design of damper devices, and the layout of external post-tensioning tendons along the bridge box girder. Fig. 3 shows the layout of external prestressing tendons in the top of box girders. Fig. 4 shows the anchor beam construction and reinforcements.

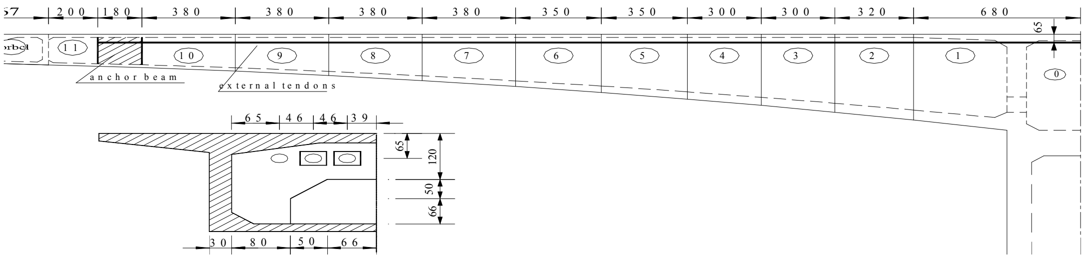
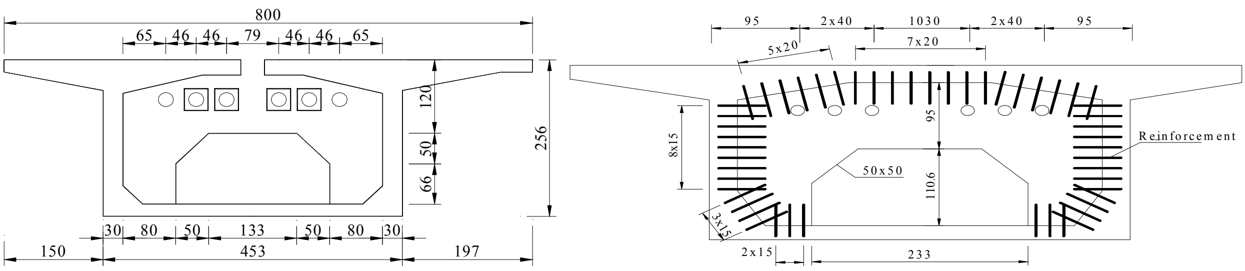


Fig. 3 Layout of external prestressing tendons



(a) (b)

Fig. 4 Anchor beam: (a) Anchor beam construction, (b) Anchor beam reinforcement

Monitoring of External Prestressing Tendons Construction Process

Monitoring of external prestressing tendons construction process includes four stages. These stages are measurement of external prestressing tendons natural frequency, monitoring of tensile forces values of external prestressing tendons, monitoring of development of anchor beams cracks, and monitoring of anchor beam deformation. In this study, monitoring process is applied for box girder No. 8 to No. 11 because of these box girders suffers from serious cracks before strengthening.

Measurement of External Prestressing Tendons Frequency. To measure the frequency of external prestressing tendons, shock observer and tensile force measurement instruments are installed. There is a correspondence relation between tension and frequency of external prestressing tendons. The relation between tension force and frequency is shown in Eq. 1:

$$T = \frac{4WL^2}{n^2 g} f_n^2 = K \cdot f_n^2 \quad (1)$$

Where:

T= tension force

W=unit weight of external tendons

L= external tendon length

n= order vibration

g= acceleration of gravity

fn= frequency

K= the proportional coefficient between external tendon tension force and frequency.

The results of frequency measurement are listed in Tables 1, 2, 3, and 4. From these tables it can be noted that the box girder No. 11 has the largest values of proportional coefficient (K) and the maximum value is 327.8. Box girder No. 8 has the largest values of frequency, the maximum value is 3.499.

Table 1 Proportional coefficient (K) for box girder No.8

Location	Left box girder		Right box girder	
Cable No.	1	2	1	2
Frequency values1(Hz)	3.393	3.497	3.496	3.495
Frequency values2 (Hz	3.383	3.538	3.509	3.499
Average frequency	3.388	3.518	3.503	3.497
Proportional coefficient	108.0	100.2	101.1	101.4

Table 2 Proportional coefficient (K) for box girder No.9

Location	Left box girder				Right box girder			
Cable No.	1	2	3	4	1	2	3	4
Frequency values11	2.082	1.965	1.939	2.136	1.965	1.945	2.109	1.974
Frequency values2	2.098	1.972	1.960	2.094	1.993	1.952	2.090	2.063
Average frequency	2.090	1.969	1.950	2.115	1.979	1.949	2.100	2.019
Proportional coefficient	283.9	320.0	326.3	277.2	316.6	326.6	281.3	304.3

Table 3 Proportional coefficient (K) for box girder No.10

Location	Left box girder				Right box girder			
Cable No.	1	2	3	4	1	2	3	4
Frequency values1	1.971	2.110	1.920	2.092	1.926	2.125	2.261	2.136
Frequency values2	1.966	2.122	2.087	2.114	2.115	2.122	2.232	2.137
Average frequency	1.969	2.116	2.004	2.103	2.021	2.124	2.247	2.137
Proportional coefficient	320.0	276.9	308.9	280.4	303.7	275.0	245.7	271.7

Monitoring of Tensile Forces Values and Elongation of external Prestressing Tendons. Five levels of tension are used in the application of tensile force in the tension process of external prestressing tendons. These levels are level 1=248.2kN, level 2=496.4kN, level 3=744.6kN, level 4=992.8kN, and level =1241kN. Each level of tension needs time more than 10min. Figs. 5, 6, 7, 8, 9, 10, and 11 shows the theoretical and measuring values of external tendons elongation for box girders No. 8, 9, 10, and 11. From these Figs. it can be noted that the measured tendons elongation values of left box girder No.8 are more than the theoretical values. For left and right box girder No. 9, side external tendons of left box No. 10, and left and right box girder No. 11, the measured values are less than theoretical values.

Table 4 Proportional coefficient (K) for box girder No.11

Location	Left box girder				Right box girder			
Cable No.	1	2	3	4	1	2	3	4
Frequency values1	1.992	2.099	1.966	2.113	1.928	2.131	1.936	1.936
Frequency values2	1.994	1.960	1.961	1.970	2.099	2.209	1.954	1.954
Average frequency	1.993	2.030	1.964	2.042	2.014	2.170	1.945	1.945
Proportional coefficient	312.2	301.1	321.6	297.5	305.9	263.3	327.8	327.8

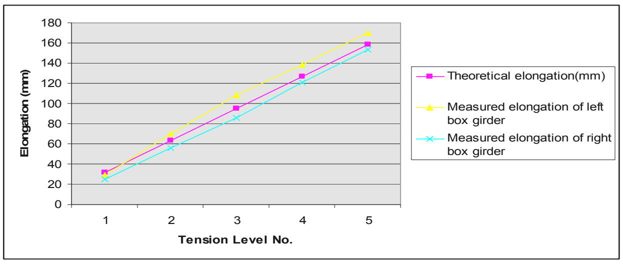


Fig. 5 Tendons elongation for box No. 8

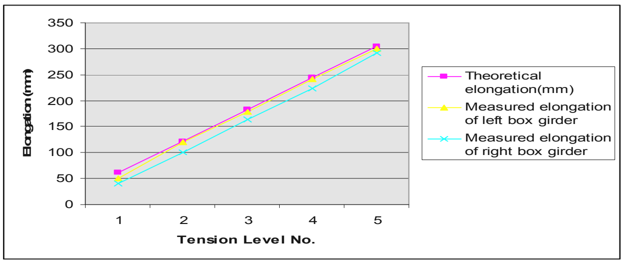


Fig. 6 Elongation of side tendons of box No. 9

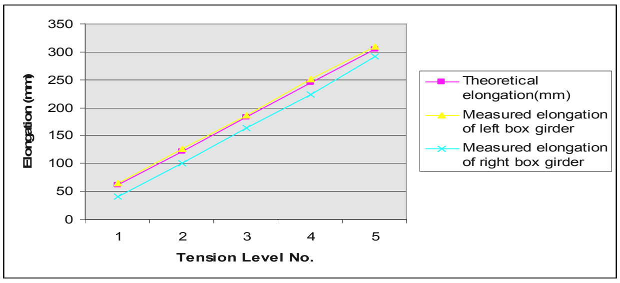


Fig. 7 Elongation of middle tendons of box No. 9

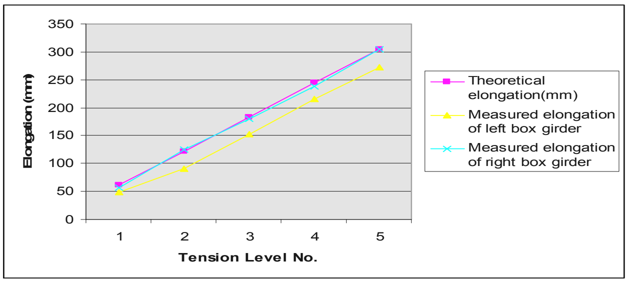


Fig. 8 Elongation of side tendons of box No. 10

Monitoring of Anchor Beam Cracks. Before applied of tension forces for external tendons, anchor beam suffers from cracks due to concrete shrinkage, vibration, and temperature. The length of these cracks rang from 5cm to 50cm, and width rang from 0.01mm to 0.25mm. Fig. 12 shows the cracks in the top and web of anchor beam. After tension process, there are no new cracks in the top, web, and bottom of anchor beam and a small number of cracks developed slightly. These cracks are found around ducts of external tendons. The length of cracks rang from 0.03m to 0.5m and width rang between 0.05 mm and 0.25mm.

Monitoring of Anchor Beam Deformation. To measure the longitudinal deformation of anchor beam, three dial gauges are used in the interface and top of anchor beam. Fig. 13 shows the location of longitudinal deformation measuring points of anchor beam. Figs. 14, 15, 16, 17, 18, 19, 20, and 21 show the values of longitudinal deformation of anchor beam during tension process of external prestressing tendons. From these Figs it can be noted that the longitudinal deformation of the interface and top of anchor beam is very small, about 0.001mm to 0.115mm, which averaged 0.026mm. The shear deformation is small and the shear capacity meets the requirements.

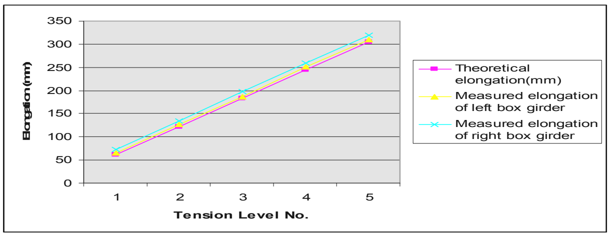


Fig. 9 Elongation of middle tendons of box No.10

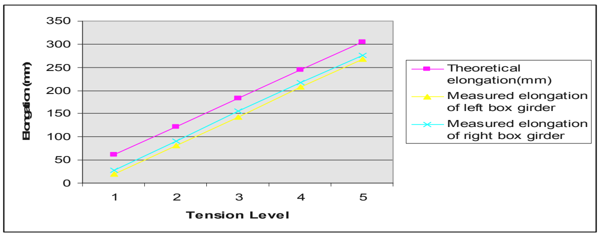


Fig. 10 Elongation of side tendons of box No. 11

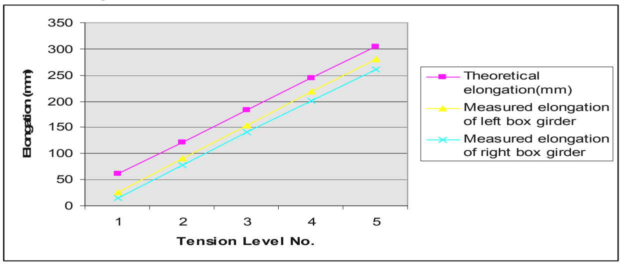


Fig. 11 Elongation of middle tendons of box No.11

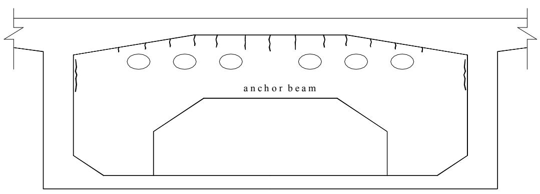


Fig. 12 Cracks in the top and web of anchor

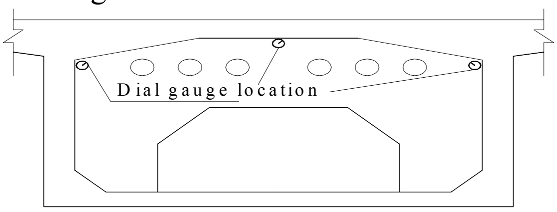


Fig. 13 Deformation measuring points

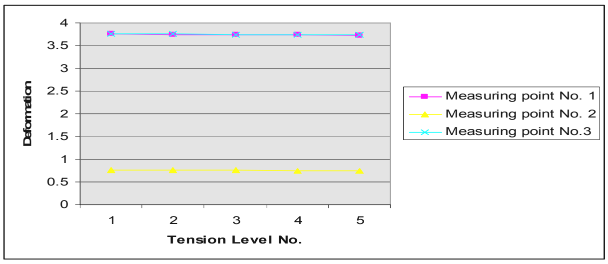


Fig. 14 Beam deformation of left box No. 8

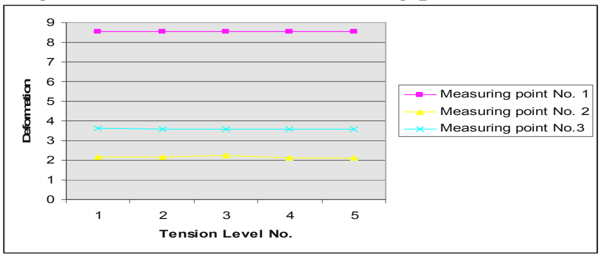


Fig. 15 Beam deformation of right box No.8

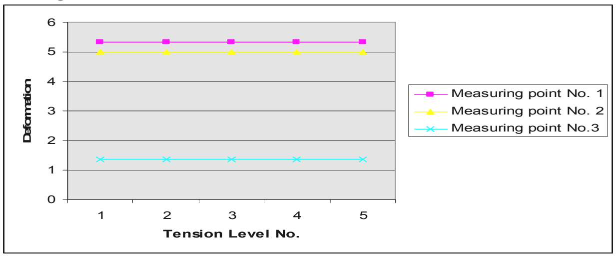


Fig. 16 Beam deformation of left box No. 9

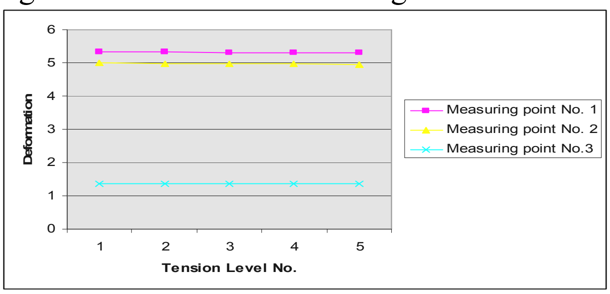


Fig. 17 Beam deformation of right box No. 9

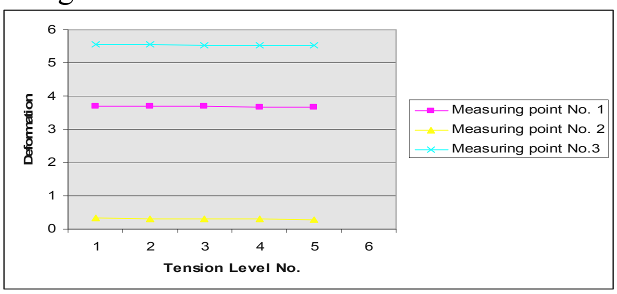


Fig. 18 Beam deformation of left box No.10

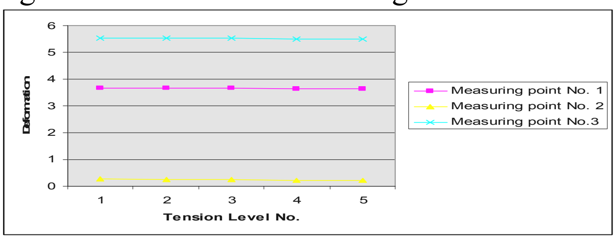


Fig.19 Beam deformation of right box No.10

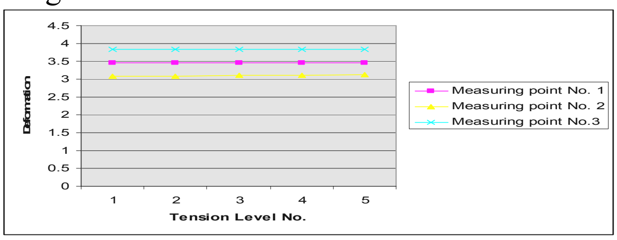


Fig. 20 Beam deformation of left box No. 11

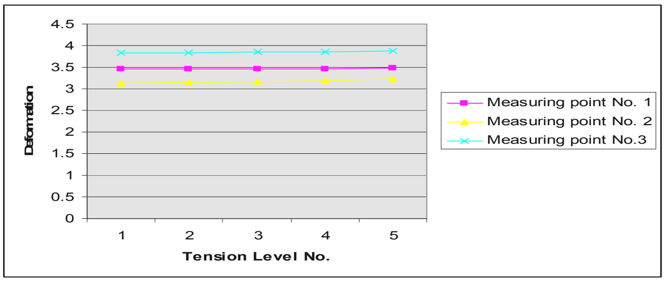


Fig. 21 Beam deformation of right box No. 11

Conclusions

The main conclusions of this study are:

1. Monitoring of external prestressing tendons construction process of Jiamusi highway prestressed concrete bridge during strengthening includes four stages. These stages are measurement of external prestressing tendons natural frequency, monitoring of tensile forces values of external prestressing tendons, monitoring of development of anchor beams cracks, and monitoring of anchor beam deformation. In this study, monitoring process is applied for box girder No. 8 to No. 11, because of these box girders suffers from serious cracks before strengthening

2. The results of monitoring process show that the box girder No. 11 has the largest values of proportional Coefficient (K) and the maximum value is 327.8. Box girder No. 8 has the largest values of frequency, the maximum value is 3.499. After tension process, there are no new cracks in the top, web, and bottom of anchor beam and a small number of cracks developed slightly. These cracks are found around ducts of external tendons. The length of cracks rang from 0.03m to 0.5m and width rang between 0.05 mm and 0.25mm. The longitudinal deformation of the interface and top of anchor beam is very small, about 0.001mm to 0.115mm, which averaged 0.026mm. The shear deformation is small and the shear capacity meets the requirements

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