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STRENGTHENING OF JIAMUSI PRE-STRESSED CONCRETE HIGHWAY BRIDGE BY USING EXTERNAL POST-TENSIONING TECHNOLOGY IN CHINA

Ali Fadhil Naser and Wang Zonglin
School of Transportation Science and Engineering, Bridge and Tunnel Engineering, Harbin Institute of Technology, China
E-Mail: ali_hu73@yahoo.com

ABSTRACT

External post-tensioning is defined as a system in which the pre-stressing tendons or bars are located outside the concrete section. The pre-stressing force is transferred to the member section through the end anchorages, deviators or saddles. The objectives of this study are to strengthen Jiamusi pre-stressed concrete highway bridge by using external post-tensioning tendons, to determine the internal forces, and to design the external post-tensioning system. Two software are used in the analysis of the T-shaped cantilever structure and anchor beam. The first is Dr. Bridge software Ver. 3.1, and the second is Ansys software Ver. 10. The results of analysis before and after laying the leveling layer of the bridge deck pavement show that the section of T-shaped cantilever structure can satisfy the demand of vehicle-20 grade and vehicle-50 grade. The compressive stress of the upper edge of pier top box section is small, it is only 1.91Mpa. Therefore, there is need to strengthen the top of the bridge deck. External post-tensioning tendons are used to strengthen the bridge deck. The selection of external post-tensioning tendons depends on the ASTMA416-90A specification. The external tendons consist of high strength, low relaxation strands, and the standard tensile strength is 1860MPa. The design and construction of external post-tensioning 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 deck.

Keywords: concrete bridges, strengthening**,** external tendons, shear stress, analysis, design, Jiamusi, China.

INTRODUCTION

The strengthening of concrete structure involves upgrading of the strength and stiffness of a structure members. The strengthening of the bridge structural members can be attempted by replacing poor quality or defective materials by better quality materials, attaching additional load-bearing materials, and re-distribution of the loading actions through imposed deformation on the structure system. The selection of an appropriate method for the strengthening and repair of the bridge structural members depends on a number of factors. The factors include the type and age of structure, the importance of structure, the magnitude of the strength required which that is need to increase, the type and degree of damage, available materials, cost and feasibility, and aesthetics [1, 2].

The pre-stressing systems can be defined as the preloading of a structure before the application of the service loads, and consist of two types of pre-stressing. The first type is known as pre-tensioning pres-stressing and the second type is known post-tensioning pre-stressing. Post-tensioning is a method of strengthening of concrete structure with high strength steel strand or bars referred to as tendons [3].

External post-tensioning is defined as a system in which the pre-stressing tendons or bars are located outside the concrete section. The pre-stressing 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 [4, 5, 6].

External post-tensioning system consists of high strength tendons, ducts, and grout pipes. Tendons are combined from steel bars or strand. Anchorage is the point where the pre-stressing force is applied and consists of anchor head or wedge plate, wedge, bearing plate, duct transition, and grout tube connections. Duct is a sheath for pos-tensioning tendons, grout pipes are attached to the duct to place concrete for internal tendons [7].

The main aim of the bridge structure strengthening by using additional external pre-stressing 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. [8, 9].

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 [10].

The objectives of this study are to explain the strengthening of Jiamusi pre-stressed concrete highway bridge by using external post-tensioning tendons, to determine internal forces, and to design the external post-tensioning system. In this study, two software are used in the analysis of T-shaped structure and anchor beam. The first is Dr. Bridge software Ver. 3.1 and the second is Ansys Ver. 10.

DESCRIPTION OF THE BRIDGE STRUCTURE

Jiamusi pre-stressed concrete highway bridge is located across the Songhua river in the Jiamusi city within Heilongjiang province in the east north of China. The total

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length of the bridge is 1396.2 m and the width is 17 m. The bridge was open to traffic in 1989. The type of bridge is T-shape rigid frame. Figure-1 shows the layout of the bridge structure and Figure-2 shows the pier and span pre-stressed box girder layout.

(a) (b) (c) (d)

Figure-1. The layout of the bridge (a) the view of bridge spans, (b) the view of T-beams and box girders, (c) the view of corbel between T-beams and box girder, (d) the view of T- beams spans.

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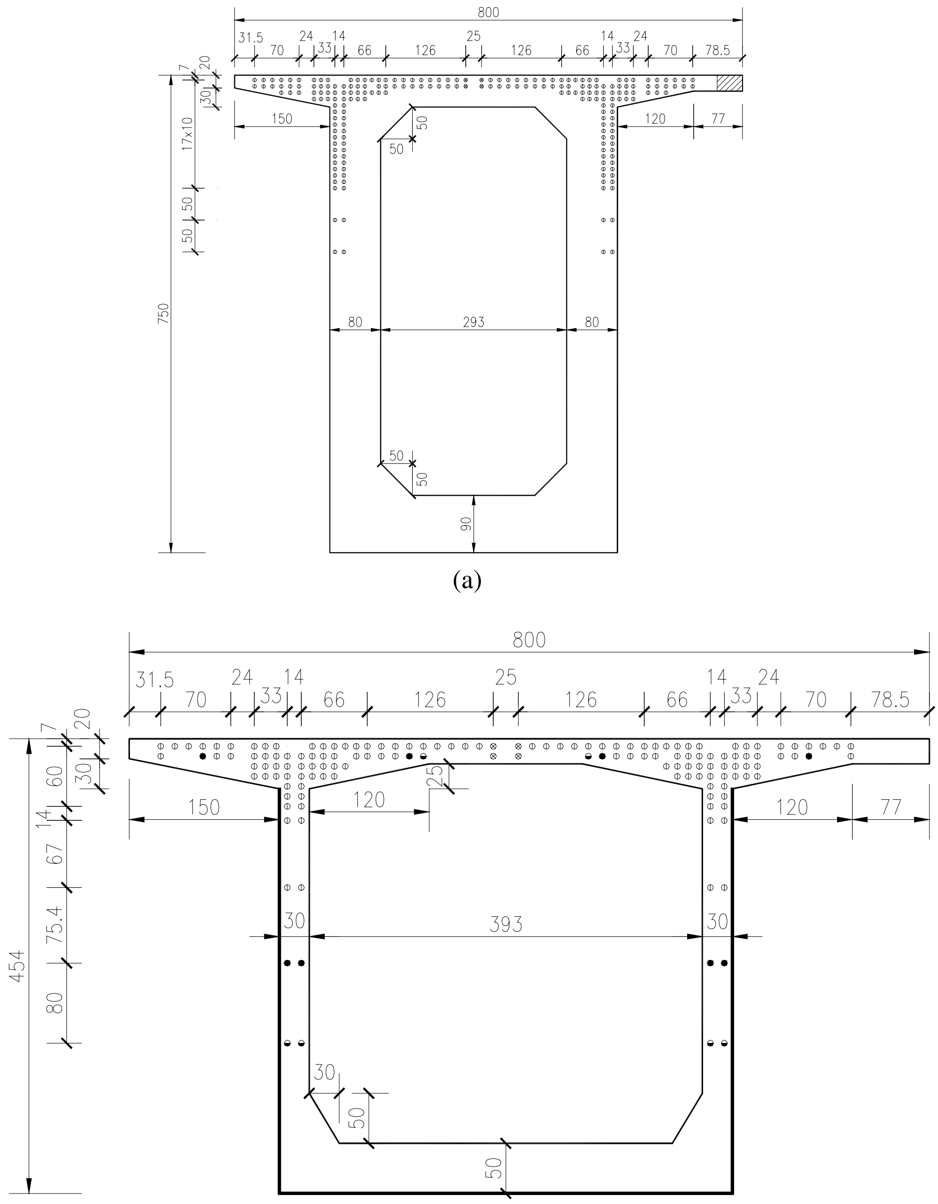

(a)

(b)

Figure-2. The box girder layout, (a) pier box girder, (b) span box girder.

PROBLEMS OF THE BRIDGE STRUCTURE

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 effect the safety and the normal using of the bridge structure. The large vibration of the bridge also mainly related with the bad smoothness of the bridge deck pavement and damages of expansion joints. The effects of creep and shrinkage of concrete related to cause the deflection in bridge structure, resulting the losing in the stiffness, resistance, and pre-stress in the main girder. Figures 3 to 9 show the damages of the bridge structural members.

Figure-3. Damage of deck pavement.

Figure-4. Down deflection of the bridge.

Figure-5. Damage of bearings.

Figure-6. Damage of corbel

Figure-7. Damage of seepage in concrete.

Figure-8. Cracks in concrete.

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Figure-9. Damage of expansion joint.

ANALYSIS OF INTERNAL FORCES

In this study, two software are used to calculate the analysis of the bridge structure. The first software is Dr. Bridge Ver. 3.1. It is used to calculate the internal forces before and after thickening the bridge deck pavement. The second software is Ansys Ver. 10. It is used to calculate the internal forces of anchorage beams which used in the strengthening of the bridge structure by using external post-tensioning pre-stressing system. The code JTJ 023-85 is adopted as a reference in the analysis of the bridge structure. The analysis process consists of two stages. The first stage is calculating the internal forces before thickening the bridge deck pavement, and the thickness is 8 cm. The second stage is calculating the internal forces after thickening the bridge deck pavement, and the thickness of leveling layer is 10cm in the parts of corbel sections and zero in the parts of pier top and suspended girder sections. This analysis adopted vehicle-20 grade and vehicle-50 grade as live loads.

Analysis of stresses under the dead loads

Figures 10 to 13 show the values of the compressive stresses in the final stage of construction of cantilever structure (i.e. after installation of hanging girders and laying leveling layer of the bridge deck pavement). From these figures, before laying the leveling layer of the bridge deck pavement, the maximum compressive stress values are 12.7 Mpa, 7.14 Mpa, 7.70 Mpa, and 6.75 Mpa for upper left edge, lower left edge, upper right edge, and lower right edge, respectively. The maximum compressive stress values after laying the leveling layer of deck pavement are 8.41 Mpa, 8.67 Mpa, 5.48 Mpa, and 8.35 Mpa for upper left edge, lower left edge, upper right edge, and lower right edge of cantilever section, respectively. All these values less than the specification of allowable compressive stress value which is 19.6 Mpa. Therefore, these values meet the requirements of JTJ 023-85 code.

Calculation: Allowable compressive stress

$= 0.7 R^{b}{}_{a} = 0.7 \times 28 = 19.6 Mpa.$

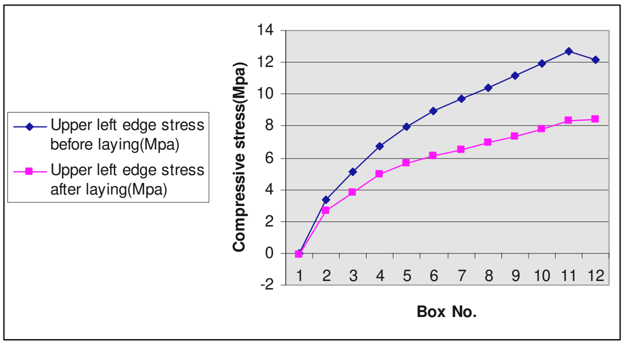

Figure-10. Compressive stress of upper left edge before and after laying.

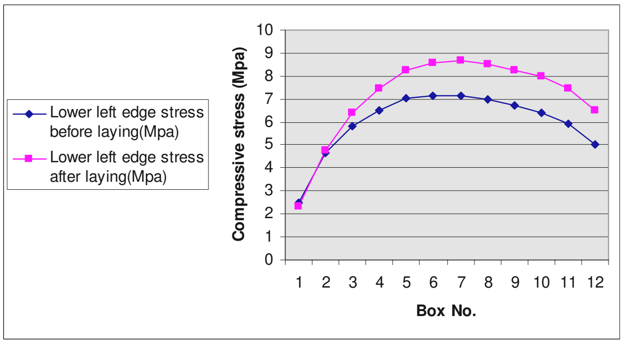

Figure-11. Compressive stress of lower left edge before and after laying.

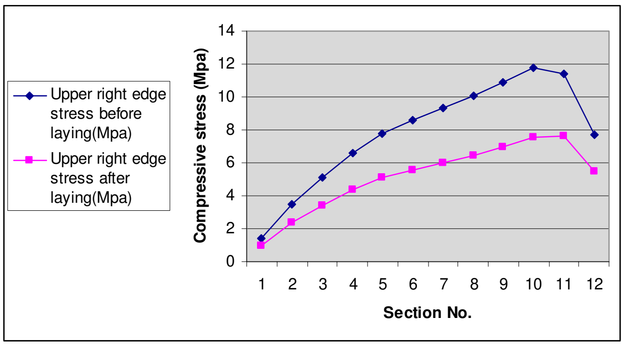

Figure-12. Compressive stress of upper right edge before and after laying.

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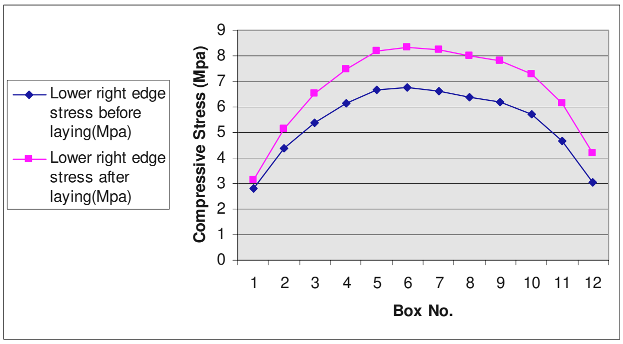

Figure-13. Compressive stress of lower right edge before and after laying.

Analysis of stresses under the combined loads at service limit state

Figures 14, 15 and 16 show the results of stress analysis under combined loads at service limit state. From these Figures, there is not tensile stress occurs in the upper and lower edge of cantilever section. The maximum normal stress value of upper edge of section is 8.14 Mpa, and the maximum normal stress of lower edge of section is 13.2 Mpa. These values are less than the specification of allowable normal stress value which is 14 Mpa.

Calculation: Allowable normal stress

$= 0.5R^b{}_a = 0.7 \times 28 = 14$ Mpa

The maximum principle stress of section is 13.2 Mpa and occurs in section No. 6 less than the limit value in the code JTJ 023-85 which is 16.8 Mpa.

Calculation: Allowable principle stress

$= 0.6R^b{}_a = 0.6 \times 28 = 16.8$ Mpa

The maximum tensile stress value occurs in the section No. 7. This value is -1.54 Mpa less than the allowable tensile stress in the code which is 2.08 Mpa.

Calculation: Allowable tensile stress

$= 0.8R^b{}_a = 0.8 \times 2.6 = 2.08$ Mpa

The results of analysis show that the values of stresses before and after laying the leveling layer of bridge deck pavement less than the allowable values in JTJ 023-85 code. Therefore, this result satisfies the requirements of the code.

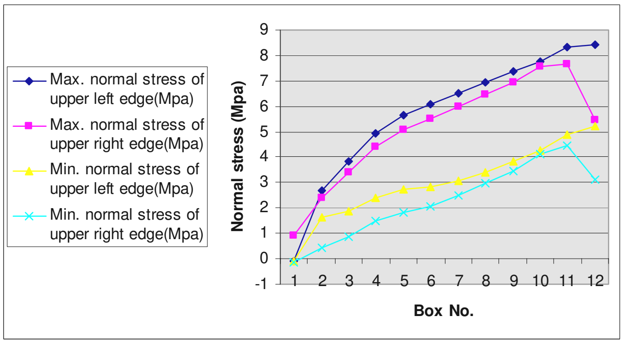

Figure-14. Normal stress of upper left and right edge.

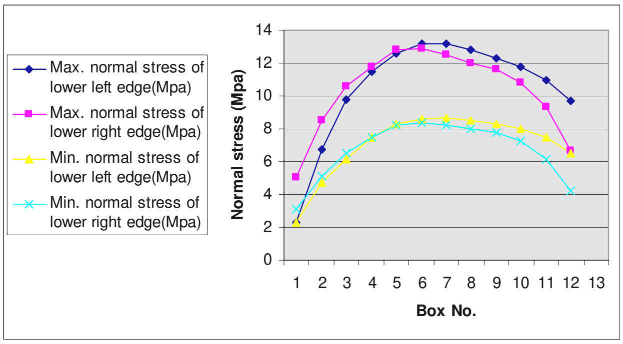

Figure-15. Normal stress of lower left and right edge.

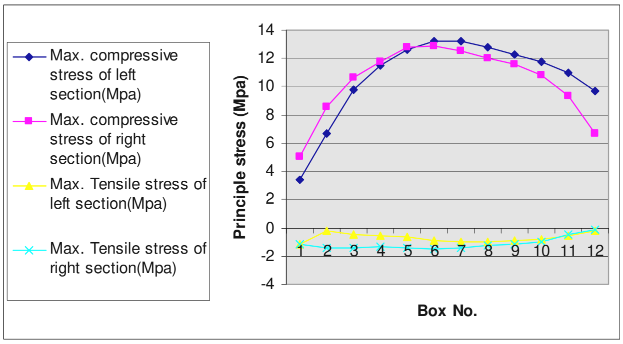

Figure-16. Compressive and tensile stress of box sections.

Analysis of bending moment

The results of bending strength moments can be shown in Figure-17. From this Figure it can be noted that, the bending strength increases after laying the leveling layer of the bridge deck pavement by 7-9%, comparing with the values before laying the layer. Therefore, the bending strength at the sections satisfies the requirements of structure ultimate limit state.

According to the results of analysis and after reforming the bridge deck pavement, the section of T-shaped cantilever structure can satisfy the demand of vehicle-50 grade and vehicle-20 grade, and the reserve of strength has a certain degree. In addition, the practical bearing capacity decreases due to the damage of the bridge structure because of the bridge has been used about 20 years, and the vehicles loads are larger than the designed vehicles loads and the compressive stress of the upper edge of pier top section is small, it is only 1.91 Mpa. Therefore, there is need to strengthen the bridge structure and increase the external post-tensioning tendons to enhance the safety and to extend the service life of the bridge structure.

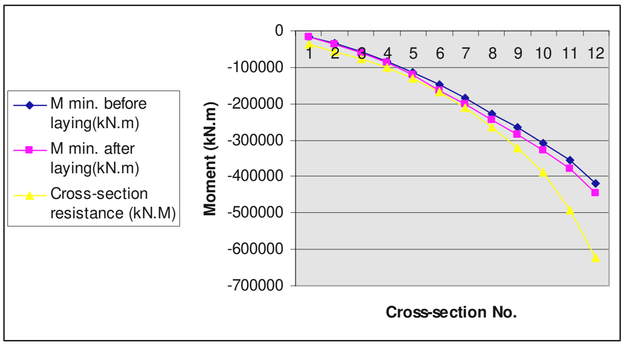

Figure-17. The Bending moments before and after laying the leveling layer.

DESIGN OF EXTERNAL POST-TENSIONING SYSTEM

The objectives of the bridge strengthening by using external pos-tensioning tendons to resist the increasing in the load due to the thickening of the bridge deck pavement, to decrease the principle tensile stress of web and positive moment of mid-span section to improve the safety and the cracks resistance and structure durability.

The design of anchor beam

The construction of anchor beams

The construction process of anchor beams includes setting of reinforced concrete beams in the top, web, and bottom of the box girder. The cross beam is located at the box No. 1. The thickness of beam is 1.8 m and the spacing between anchor beam and corbel diaphragm is 2.30 m. The anchor beam and the original box girder are connected by using embedding steel re-bars. Figure-18 shows the construction of anchor beam.

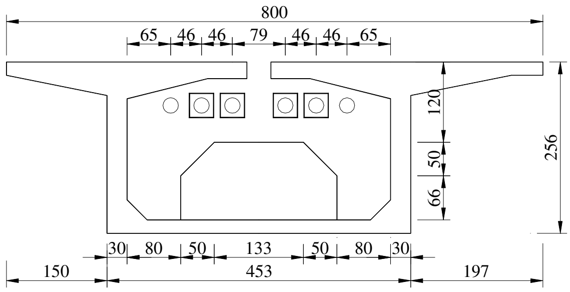

Figure-18. The construction of anchor beam.

Analysis of anchor beam

Using solid 95 block element of Ansys Ver. 10 to analyze the forces of anchor beam and to calculate the tension forces in external tendons. Figure-19 shows model of anchor beam. The results show that the design tension force of external tendon was controlled to 40% and the ultimate tension force of each tendon is 1250 kN. The calculation of external tendon tension force is controlled to 50% and the ultimate tension force is 1560kN. The shear stress increases from the box girder top to the center of web and the maximum shear stress is 2654.8 kPa and occurs in the center of upper supporting. The maximum shear stress of the web is 3311.5 kPa and occurs in the junction of lower supporting and web. The shear stress of bottom of box girder is small and the maximum value is 2148.1 kPa. The maximum shear stress of the anchor beam and box girder contact points occurs near the anchor plane along the beam thickness direction.

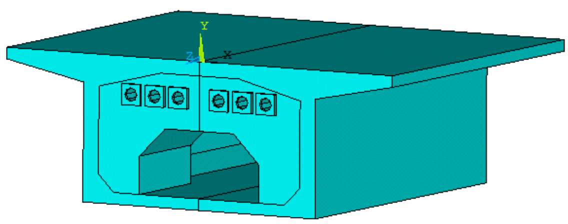

Figure-19. Model of anchor beam.

The design of re-bars of anchor beam

The maximum shear stress of top, web, and bottom of box girder are used to design the anchor beam re-bars. Adopting Φ16×190 HRB335 with diameter 160 mm as implanted re-bars. The depth of anchoring is 19 cm. the design of bolt shear force is 33 kN. The results of the anchor beam re-bars design are listed in Table-1. Figure-20 shows the anchor beam reinforcement.

Table-1. The results of the anchor beam re-bars design.

Components of box girder	**Length** (m)	**Shear stress** (kPa)	**Concrete shear stress** (kPa)	**Steel bar shear force** (kN)	**No. of bars**	**Spacing** (m)
Top	4	2654.8	1920	5290.6	160.3	0.212
Web	3.05	3311.5	1920	7639.3	231.5	0.154
Bottom	1.848	2148.1	1920	758.8	23	0.380

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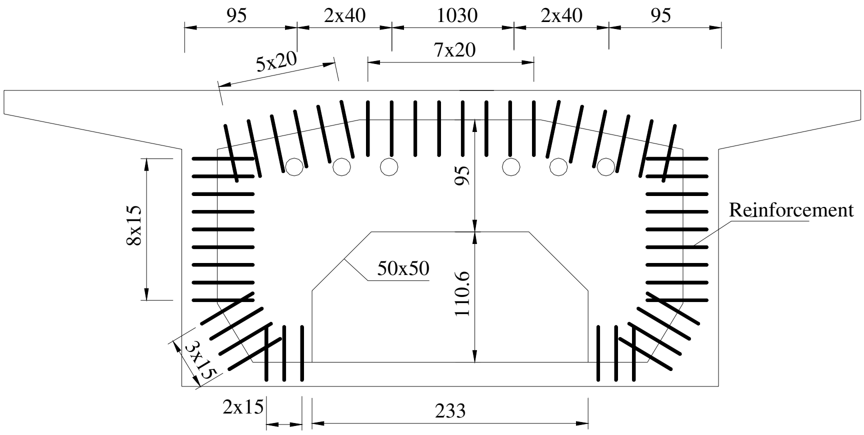

Figure-20. The anchor beam reinforcement.

The design of damper devices

When the vehicles use the bridge structure, vibrations will produce, resulting in the vibration of external post-tensioning tendons. If the vibration of external tendons is excessive, it leads to change the tensile stresses of external tendons. Therefore, the vibration damping is used to reduce the effects of vibrations. Figure-21 shows the structure of external tendons damper.

The layout of external post-tensioning tendons

The properties of external tendons must meet the ASTMA416-90A specification. The external tendons consist of high strength and low relaxation strands, and the standard tensile strength is $R_y^{\ b} = 1860 Mpa$. External tendons must have enough resistance to corrosion and other environmental conditions. Φ 15.24-12 cables with OVM TSK-VI tension are used as a external tendons in the strengthening process. The tension stress is 744 Mpa.

Calculation: $\sigma_k = 0.4 R_y^{\ b} = 0.4 \times 1860 = 744 Mpa$

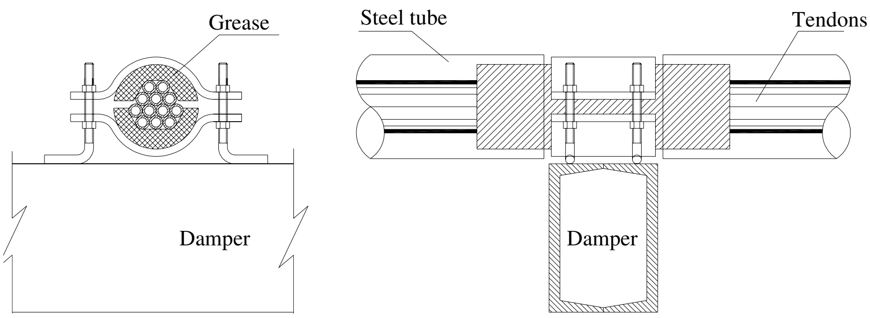

Figure-21. The structure of external tendons damper.

The tension tonnage of each cable is 125 tons. Each box layout 2 lines on each side, set along the long straight line of T -shaped structure by reset, the distance of the top side of the section to external cable is 65 cm. In box No. 1, anchorage beams are installed and set 6 channels in cross beam, two of these channels near the web of box section. Figure-22 shows the layout of external post-tension tendons.

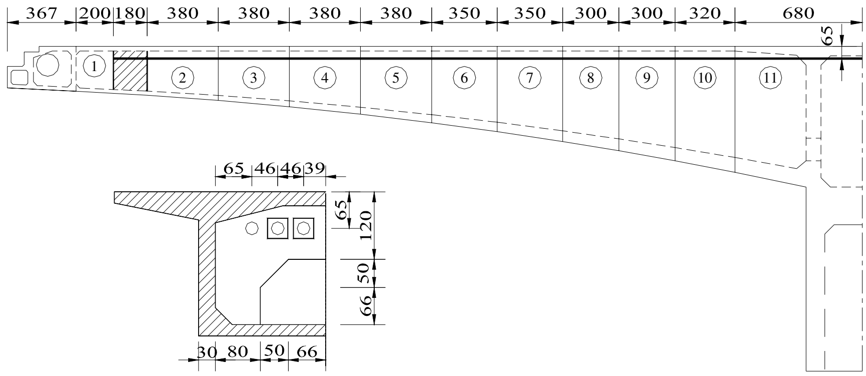

Figure-22. The layout of external post-tension tendons.

CONCLUSIONS

The main conclusions that can be drawn from this study are:

a) Damage inspection results of the bridge structure show that the corbel in end of cantilever 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 affect the safety and the normal using of the bridge structure. The large vibration of the bridge also mainly related with the bad smoothness of the bridge deck pavement and damages of expansion joints. The effects of creep and shrinkage of concrete related to cause the deflection in bridge structure, resulting the losing in the stiffness, resistance, and pre-stress in the main girder.
b) Dr. Bridge Ver. 3. 1 and Ansys Ver. 10 are used in the analysis process. According to the results of analysis before and after reforming the bridge deck pavement, the section of T-shaped cantilever structure can satisfy the demand of vehicle-20 grade and vehicle-50 grade grade, and the reserve of strength has a certain degree. In addition, the practical bearing capacity decreases due to the damage of the bridge structure because of the bridge has been used about 20 years, and the vehicles loads are larger than the designed vehicles loads and the compressive stress of the upper edge of pier top section is small, it is only 1.91 Mpa. Therefore, there is need to strengthen the bridge deck and increase the external post-tensioning tendons to enhance the safety and to extend the service life of the bridge structure.
c) The strengthening of the bridge deck includes using the external post-tensioning tendons to resist the increasing in the load due to the thickening of the bridge deck pavement, to decrease the principle tensile stress of web and positive moment of mid-span section to improve the safety and to improve the cracks resistance and structure durability. The selection of external post-tensioning tendons depends on the ASTMA416-90A specification. The external tendons consist of high strength, low relaxation strands, and the standard tensile strength is $R_y^{\ b} = 1860Mpa$.
d) The design and construction of external post-tensioning 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 deck.

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