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Theoretical Analysis of Designed Internal Forces of Jiamusi Highway Prestressed Concrete Bridge before Strengthening in China

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Abstract. The objective of this study is to calculate and analyze the internal forces under designed dead and live loads to evaluate the structural performance of corbels and T-shaped cantilever structure of the main span of Jiamusi highway prestressed concrete bridge to evaluate the state of the structural members of the bridge. Two software are used in this analysis. The first software is Dr. Bridge Ver. 2.95 which is used to analyze the internal forces of T-shaped cantilever structure under different load combinations. The second software is Ansys Ver. 10 which is used to analyze the internal forces in the corbel. The results of analysis show that at the dead load stage, the maximum compressive stress at the upper and bottom edge of all sections of T-shaped cantilever structure satisfies the allowable values of standard. The tensile stress doesn't appear. At the normal service stage, there is enough reserve of compressive stress in the all sections, and the compressive stress is smaller than the allowable value of the standard. There is no tensile stress for all the controlled sections. The maximum main compressive stress and maximum main tensile stress of all controlled sections is smaller than the allowable value of standard. The bending strength of all sections satisfies the allowable values of standard, and there is big reserve of strength. The steel settled in the oblique section of 45° in the web of the corbel has enough reserve for the tensile strength. If the prestressed steel in the corbel is inefficient, the resistance of the oblique section given by the ordinary steel in the corbel and it can be resisted the loads. The longitudinal positive stress of vertical section a-b, vertical shear stress, main tension stress and main tension stress of oblique section a-c of 45 satisfy the allowable values of standard.

Introduction

A bridge is the most important part of transportation infrastructure. The conception, development and worldwide construction of bridges represents the most interesting and important achievements in civil engineering. Their safe, efficient and economic operation requires that the bridges be designed and constructed so they can be operational with routine maintenance for an extended design life. [1]

The most important factor in the whole life design of reinforced and prestressed concrete bridges is the service limit state. This fact has principal importance for serviceability, durability and long-time reliability of the bridges. [2]

Bridge structural analysis commonly involves computer models, which use appropriate material properties, boundary conditions, and loads. Members and connections joints are proportioned to carry all possible loads (permanent loads, vehicular live loads, wind loads, and earthquake loads), combined and factored in accordance with the requirements of applicable design standards and codes. [3]

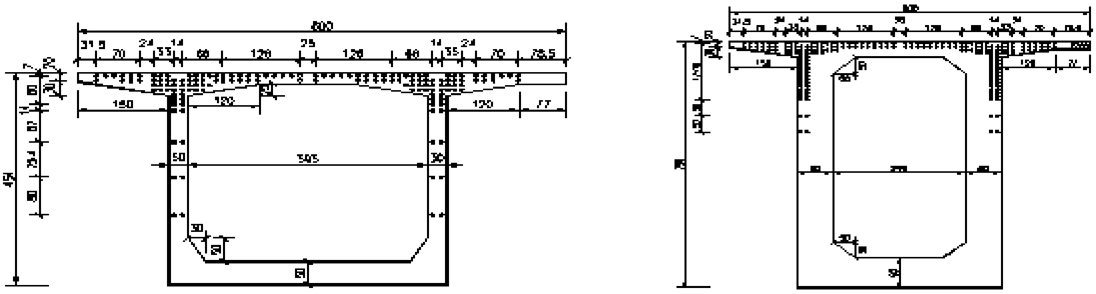
Jiamusi highway prestressed concrete bridge is located in the Jiamusi City within Heilongjiang province in the east north of China. The bridge crosses a Songhua river. The overall length of the bridge is 1396.2m and the total width of transverse section of the bridge is 17m. The bridge is kind of

T-shaped rigid frame structure with hanging beams and simply supported T-beams. The bridge structure is made from prestressed concrete box girder and prestressed concrete T-beams. The bridge was open to traffic in September 1989. Fig. 1 shows the view of the bridge structure and Fig. 2 shows the sections of box girder.

The objective of this study is to calculate and analyze the internal forces under designed dead and live loads to understand the structural properties of T-shaped cantilever structure of the main span of Jiamusi highway prestressed concrete bridge to know the state of the structural members of the bridge.

(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

Conditions of Loads

The analysis process is carried out depending on the design code of highway prestressed concrete bridge and culverts [4]. The T-shaped cantilever is divided into 38 stages according to construction process. The conditions of loads which are adopted in this study include:

a) Load combination I=dead load + car load + crowed load (3.5kN/m) + support friction force
b) Load combination II=dead load + hanging car load
c) Load combination III=dead load + crowed load (3.5kN/m)

Analysis of Internal forces of T-shape Cantilever Structure

In this analysis, Dr. Bridge software Ver. 2.95 is used to analyze the internal forces of the T-shaped cantilever structure due to dead load, live load, prestressed load, temperature load, support friction load, and creep and shrinkage load. Fig. 3 shows the model of T-shaped cantilever structure.

Analysis of Internal Forces at Different Construction Stage Due To Dead Load. Figs. 4 and 5 show the internal forces and cumulative stresses before and after complete construction process. From these Figs it can be noted that the maximum axial force is 97100 kN in the section No. 1 of pier box girder before complete construction process but this value decreases to 96810kN after complete construction process. The maximum bending moment is 172600kN.m in the section No. 1 of pier box girder before complete construction process, and also this value decreases to 74660kN.m. The maximum of compressive stress for all parts of box girders in T-shaped cantilever structure is 16.9 Mpa in the joint between box girder No. 1 and 2, less than the allowable value in the standard (0.7Rab=0.7x28=19.6Mpa). The minimum compressive stress is 0.07Mpa at the lower right edge of pier box girder No.1. After the complete of construction process, the maximum compressive stress is 7.7Mpa in the upper right edge of pier box girder No. 1. For left edge, the maximum compressive stress is 7.14Mpa in the lower left edge of box girder No. 7. All maximum compressive stress values less than the standard value.

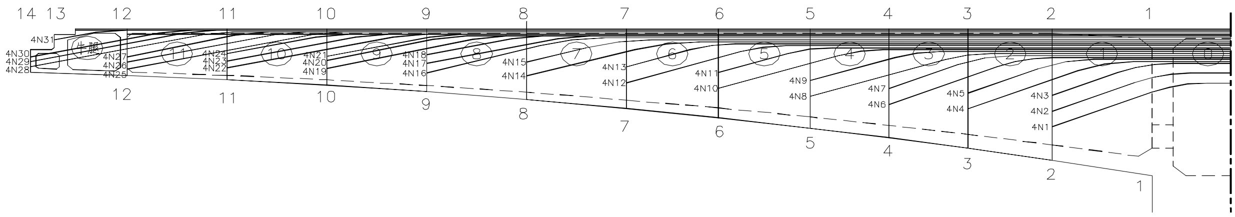
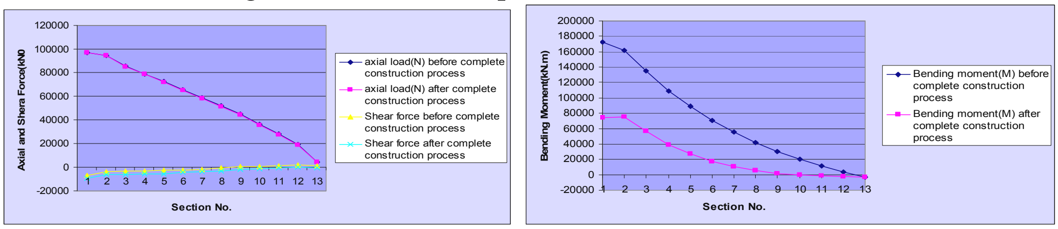
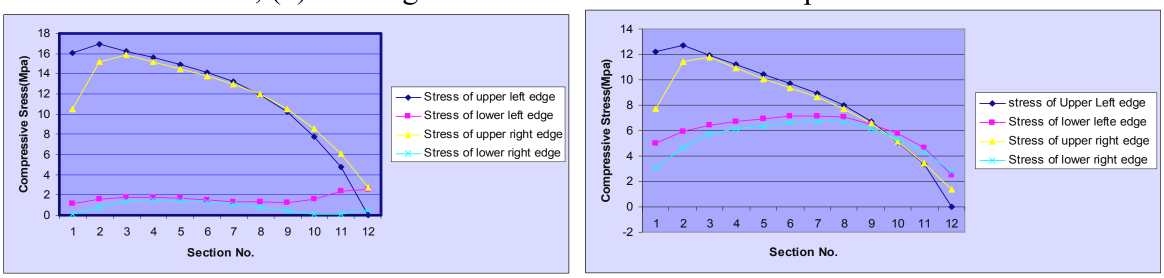


Fig. 3 Model of T-shaped cantilever structure.



(a) (b)

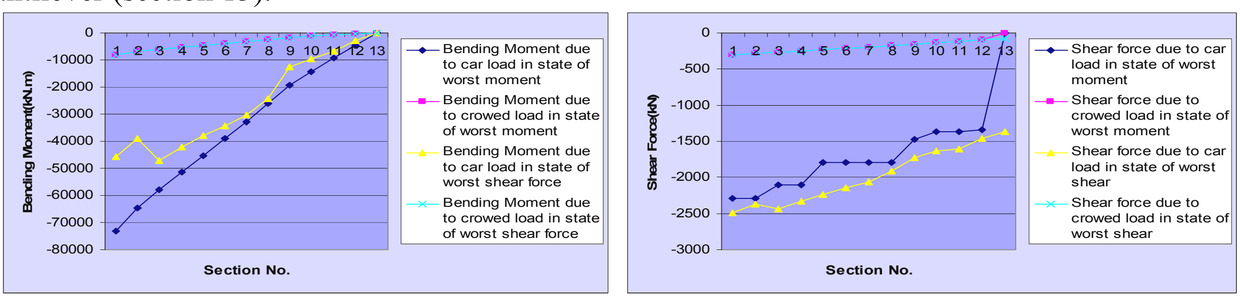
Fig. 4 Internal forces due to dead load: (a) axial and shear forces before and after complete construction, (b) bending moment before and after complete construction



(a) (b)

Fig. 5 Cumulative stress: (a) Stress before complete construction, (b) Stress after complete construction

Analysis of Internal Forces Due to Live Load. Figs 6 and 7 show the internal forces due to live load (car-20 grade and crowded load 3.5 kN/m). From these Figs it can be noted that the values of bending moment and shear force less than the allowable values of standard, and the maximum value of vertical deflection is 19mm in up direction and 58.8 in under car-20 grade load in the end of T-shaped cantilever (section 13).



(a) (b)

Fig. 6 Internal force due to live load: (a) bending moment in states of worst moment and shear, (b) shear force in states of worst moment and shear

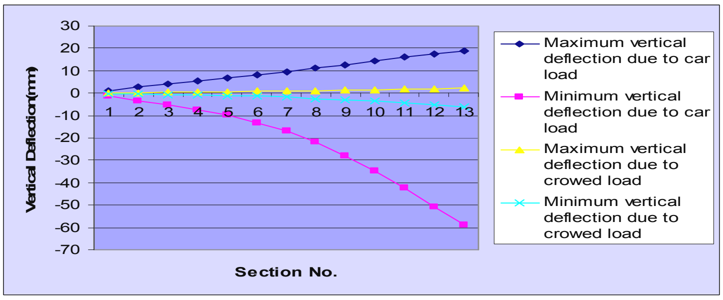
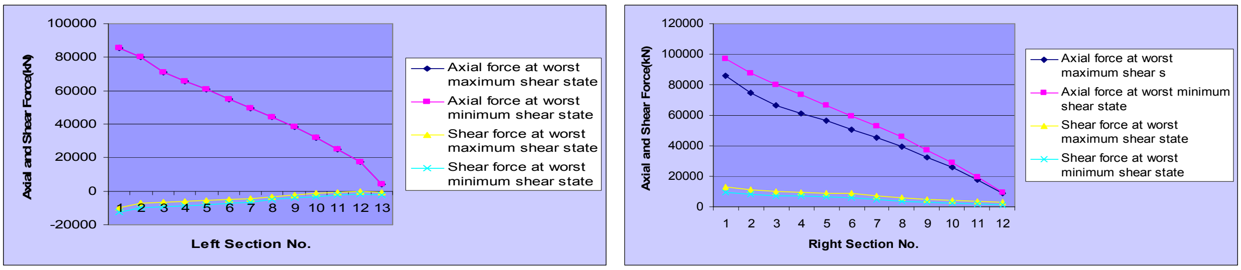


Fig. 7 Vertical deflection due to live load (mm)

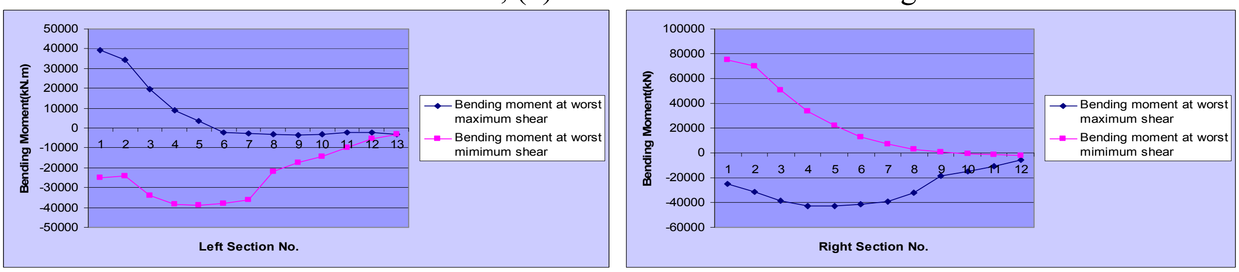
Analysis of Internal Forces Due to Load Combination I at Normal Service Stage. Figs. 8, 9, 10, 11, and 12 show the analysis results of internal forces due to load combination I at normal service stage. The results show that the values of tensile stress are very small in all sections of T-shaped cantilever structure. The minimum normal stress at the upper edge of the pier box girder of T-shaped cantilever structure cantilever section is 3.8MPa, having enough reserve of compressive stress. The maximum normal stress at the lower edge of all sections is 12.1MPa, smaller than the limited value of the standard (0.5Rab=0.5x28=14.0MPa), and the maximum normal stress at the upper edge of all sections is 12.7MPa, satisfying the allowable values of standard. The maximum main compressive stress of all controlled sections is 12.7MPa, smaller than the limited value of the standard (0.6Rab=0.6x28=16.8MPa). The maximum main tensile stress is 1.22MPa, smaller than the limited value of the standard (0.8Rlb=0.8x2.6=2.08MPa). The stirrup spacing calculated by the main tensile stress is much bigger than the original spacing 15cm, indicating than the capacity of main tensile resisting stress of web is enough.



(a) (b)

*Section No. 13 is corbel section and section No. 1 is pier box girder

Fig. 8 Internal forces due to load combination I at normal service stage at worst shear: (a) axial and shear forces of left sections, (b) axial and shear forces of right sections

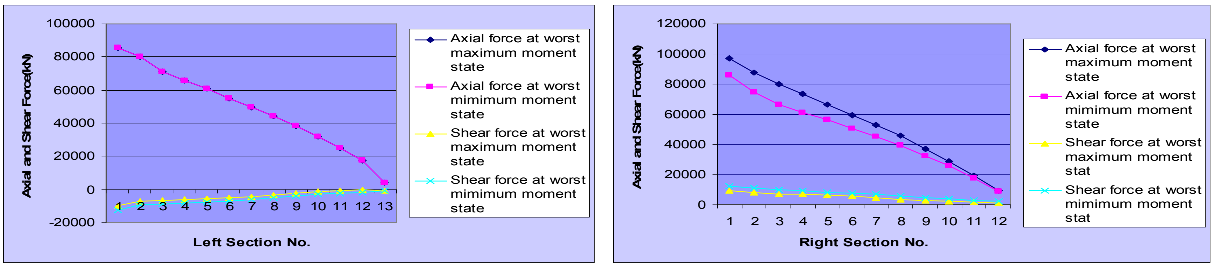


(a) (b)

*Section No. 13 is corbel section and section No. 1 is pier box girder

Fig. 9 Bending moment due to load combination I at normal service stage at worst shear: (a) bending moment of left section, (b) bending moment of right section

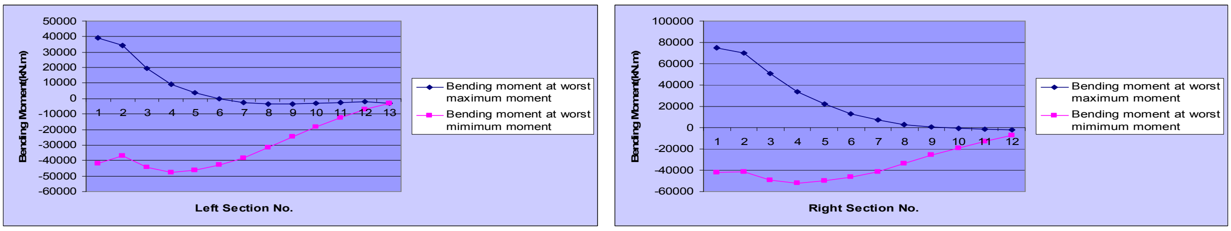
Analysis of Cross Section Resistance (Flexural Strength). Fig. 13 shows the comparison between the actual designed bending moment and the worst bending strength. From this Fig. it can be noted that the worst bending strength for all sections of T-shaped cantilever structure are small than the actual designed bending strength, indicating that there is enough reserve of strength and the bending strength satisfies the allowable values of standard when the structure is undertaken the service loads.



(a) (b)

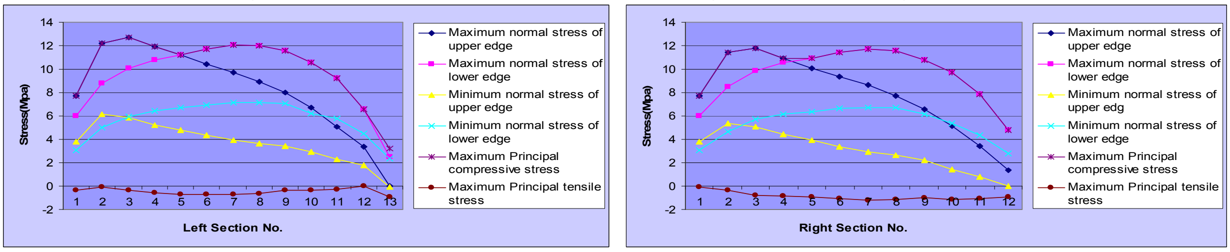
*Section No. 13 is corbel section and section No. 1 is pier box girder

Fig. 10 Internal forces due to load combination I at normal service stage at worst moment: (a) axial and shear forces of left sections, (b) axial and shear forces of right sections



Section No. 13 is corbel section and section No. 1 is pier box girder

Fig. 11 Bending moment due to load combination I at normal service stage at worst moment: (a) bending moment of left section, (b) bending moment of right section



(a) (b)

Fig. 12 Stress distribution of load combination I stage: (a) stresses of left section, (b) stresses of right section

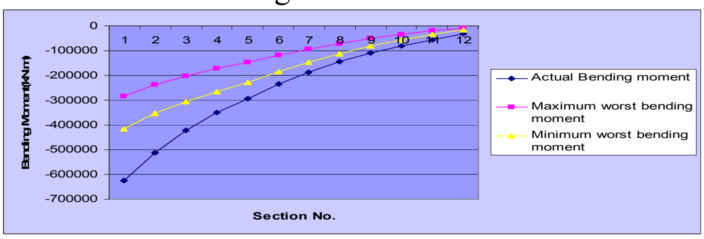


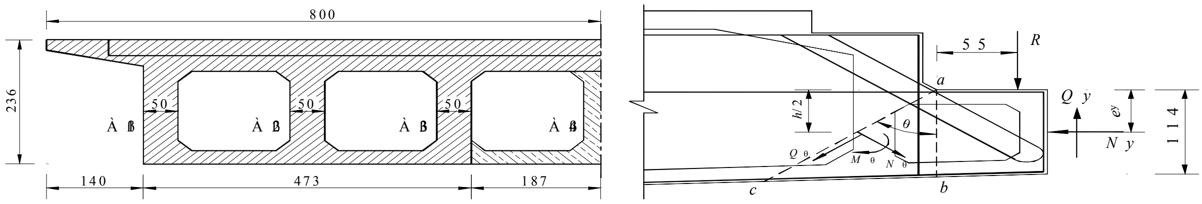
Fig. 13 Actual designed bending strength, and worst maximum and minimum bending moment of T-Shaped cantilever structure

Analysis of Corbel Internal forces

Analysis of Bearing Reaction of Corbel. There are 7 hanging beams in the transverse section of the bridge and every corbel has 7 webs. The positions of rib of hanging beams and webs of the corbel align for each other. The reaction of the hanging beams directly transfers to the cantilever of corbel. Fig. 14 shows corbel and hanging beam structures and Fig. 15 shows the diagram of corbel structure and bearing reactions forces. Fig. 16 shows the results of bearing reaction force of every hanging beam in the corbel. From Fig. 16(a) it can be noted that the maximum reaction is 500.4kN within hanging beams No. 2 and 6 due to trailer live load, and from Fig. 16(b) it can be seen that the maximum bearing reaction is 872.4kN and 1135.2kN for load combination I at normal and ultimate limit state respectively in hanging beam No. 1.

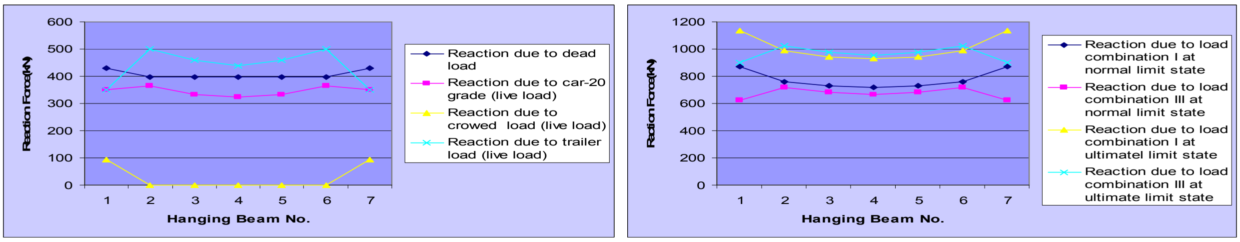
(a) (b)

Fig. 14 Corbel and hanging beams structures: (a) corbel, (b) 7 hanging beams



(a) (b)

Fig. 15 Corbel structure: (a) diagram of corbel structure, (b) bearing reactions forces



(a) (b)

Fig. 16 Bearing reactions of hanging beams: (a) bearing reactions due to dead and live load, (b) bearing reactions due to load combination I and III at normal and ultimate limit state

Analysis of Tensile Strength of Oblique a-c Section. As shown in Fig. 15(b), the total oblique tensile strength (Z) can be calculated by using Eq. 1:

$$Z = \frac{R}{\cos 45} \tag{1}$$

Where:
Z= total oblique tensile strength
R=vertical force
The total oblique tensile strength (Z) must be satisfied the condition shown in Eq(2):

$$KZ \leq \sum (R_g \times A_{gw(45^o)}) \tag{2}$$

Where:
K= safety coefficient of tensile strength is 1.45
$A_{gw(45^o)}$ =the projection area of oblique section

The results of tensile strength and steel resistance at the oblique section in the corbel are listed in Tables 1 and 2. From these tables it can be noted that the steels at the oblique section of 45° in the web have enough reserve of the tensile strength. If the prestressed steel in the corbel has failure, only the resistance of oblique 45° section given by the ordinary steel in the corbel can satisfy the demand of the load. Rib No. 2 is the inner web of the box girder and rib No. 4 is in the joint of two box girders. There is no steel passed through the prestressed steel. Therefore, the tension capacity of the oblique section decrease, but the value of the tension is still bigger than Z of limited combination III (Z=1025.2kN). In addition, in the Table, the calculation of undertaking force doesn't include the function of concrete and stirrup. If considering the influence of concrete and stirrup, the undertaking capacity of the oblique section will further increase.

Table 1 Tensile strength and steel reinforcement for ordinary steel

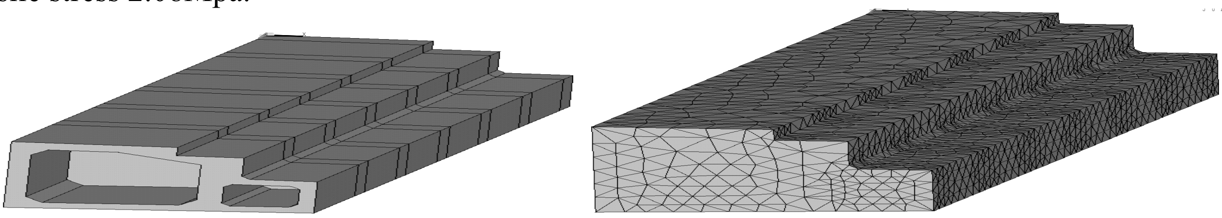
Rib No.	45^o oblique tendons	Horizontal steel reinforcement	Vertical steel reinforcement	Projected area(cm^2)	Tensile strength
1	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	2621.1
2	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	1335.4
3	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	2621.1
4	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	1335.4
5	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	2621.1
6	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	1335.4
7	4ϕ 25	2ϕ25+14ϕ8	2ϕ25+14ϕ16	56.95	2621.1

Table 2 Tensile strength and prestressed tendons for ordinary steel

Rib No.	No. of tendons	Horizontal angle	Project area(cm^2)	Tensile strength(kN)
1	6 tendons 24Φ_s	14°	14.565	2621.1
2	-	-	0	1335.4
3	6 tendons 24Φ_s	14°	14.565	2621.1
4	-	-	0	1335.4
5	6 tendons 24Φ_s	14°	14.565	2621.1
6	-	-	0	1335.4
7	6 tendons 24Φ_s	14°	14.565	2621.1

Analysis of Stresses. Ansys ver. 10 is used to analyze stresses in the corbel structure. The finite element model is built by making the front end of corbel is free and the back end is fixed. Fig. 17 shows the solid model of corbel and model of finite element analysis. Fig. 18 shows the variation of longitudinal positive stress (δx) in the vertical shear a-b section of all ribs in the corbel under load combination I. From this Fig. it can be noted that the section a-b is always at the compressed state. The maximum compressive stress is located in the half height of the corbel. The maximum stress value is 3.65MPa in the rib No. 1. The minimum compressive stress is 0.95MPa, and located in the corner point of the corbel. There is no prestressed steel in the rib No. 2 and ribs No. 4. Therefore, the a-b section is subjected to bending. The maximum tensile stress on the top edge of the section is 1.174MPa, smaller than the allowable value (0.8Rlb=2.08MPa), indicating that the stress values satisfy the values in standard for the partially prestressed concrete-A component.

Fig. 19 shows the variation of shear stress (τxy) in the vertical shear a-b section of all ribs in the corbel under load combination I. From this Fig. it can be seen that the maximum direct shear stress for the ribs No. 1 and 3 is 0.94MPa, and for Ribs No. 2 and 4 is 91MPa. All the shear stress values are smaller than the allowable shear stress of concrete type C-40 ([σj] =2.4MPa). Figs. 20 and 21 show the variation of main tensile stress (σ1) in vertical a-b section and oblique a-c section of ribs in the corbels under load combination I. These Figs. show that because of there is not prestressed steel passing through the ribs No. 2 and 4, the main tensile stress is bigger than that of ribs No. 1 and 3. The maximum main tensile stress of ribs No. 2 and 4 is 2.05MPa, and located in the corner point of upper edge of the corbel. This value is smaller than the allowable tensile stress value 0.8Rlb=2.08MPa, satisfying the standard value for the main tensile stress of the bending component of the prestressed concrete. When the distance of corbel height (d) increases, the main tensile stress decreases significantly. When d is 0.2m, the main tensile stress is about 1.2MPa, much smaller than allowable tensile stress 2.08Mpa.



(a) (b)

Fig. 17 Corbel model: (a) solid model, (b) finite element analysis model

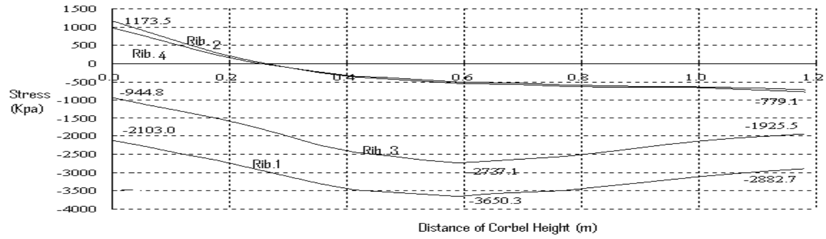


Fig. 18 Variation of longitudinal positive stress δx in the vertical shear a-b section of all ribs in the corbel under load combination I

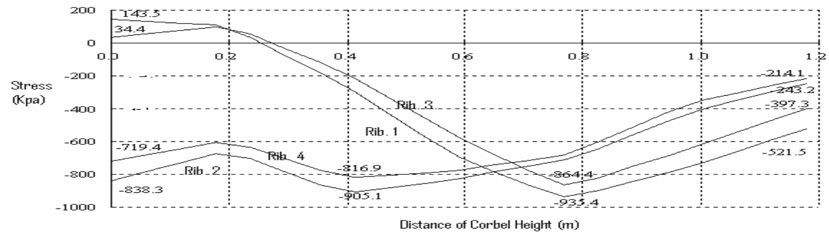


Fig. 19 Variation of shear stress τxy in the vertical shear a-b section of all ribs in the corbel under load combination I

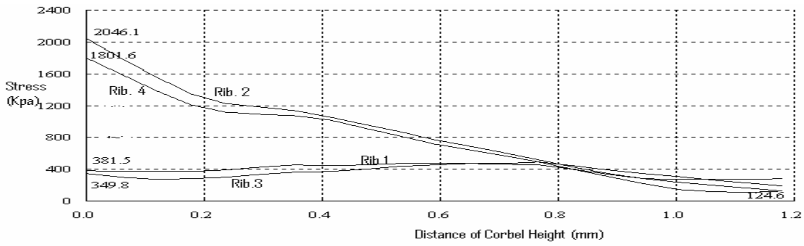


Fig. 20 Variation of main tensile stress σ1 in vertical a-b section of ribs in the corbels under load combination I

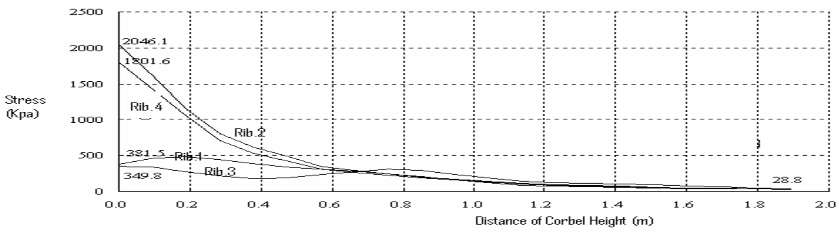


Fig. 21 Variation of main tensile stress σ1 in oblique a-c section of ribs in the corbels under load combination I

Conclusions

The main conclusions of this study are:

1) Dr. Bridge software Ver. 2.95 is used to analyze the internal forces of the T-shaped cantilever structure due to dead load, live load, prestressed load, temperature load, support friction load, and creep and shrinkage load. The results of analysis show that at the dead load stage, the maximum compressive stress at the upper and bottom edge of all sections of T-shaped cantilever structure satisfies the allowable values of standard. The tensile stress doesn't appear.
2) At the normal service stage, there is enough reserve of compressive stress in the all sections, and the compressive stress is smaller than the allowable value of the standard. There is no tensile stress for all the controlled sections. The maximum main compressive stress and maximum main tensile stress of all controlled sections is smaller than the allowable value of standard. The bending strength of all sections satisfies the allowable values of standard, and there is big reserve of strength.
3) Ansys Ver. 10 software is used to analyze the internal forces in the corbel. The results show that the steel settled in the oblique section of 45° in the web of the corbel has enough reserve for the tensile strength. If the prestressed steel in the corbel is inefficient, the resistance of the oblique section given by the ordinary steel in the corbel and it can be resisted the load. The results of the finite element analysis indicate that the longitudinal positive stress of vertical section a-b, vertical shear stress, main tension stress and main tension stress of oblique section a-c of 45 satisfy allowable values of standard.

References

[1] Educational Program Innovation Center (EPIC), *Planning, Design, and Rehabilitation of Bridge*, EPIC Learning Centre: 5759 Coopers Avenue, pp. 1-6. Mississauga, ON L4Z 1R9, September, (2010).

[2] K. Vladimír, and K. Alena, *Theoretical Analysis of RC. Bridges, Prediction of Long-term Behavior Modern Computational Models*, Center of Integrated Design of Advanced Structure, This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No. 1M0579, (2005).

[3] L. Duan, *Highway Bridge*, in AccessScience@McGraw-Hill, ttp://www.accessscience.com, DOI 10.1036/1097-8542.800420, (2008).

[4] JTJ023-85, Code *for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts*. People's Republic of China, (1985).