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EFFECT OF TRANSVERSE TEMPERATURE GRADIENT ON JAMUNA BRIDGE OF BANGLADESH

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ABSTRACT

Bridge structures are subjected to continuous heating and cooling from the surrounding environment and solar radiation. This may cause undesired deformations and stresses in the bridge section. The non-linear variation in temperature across the bridge cross-section leads to thermal stresses, which can seriously affect the serviceability and the structural integrity of bridge structures. In box girder bridges the temperature induced stresses are more severe due to the presence of a closed air cell inside the box section. The Bongobondhu Jamuna Multipurpose Bridge of Bangladesh is the 12th longest bridge in the world. It is a prestressed balanced cantilever bridge consisting of box girder section. An attempt has been made in this study to perform a three dimensional finite element analysis of the Jamuna Bridge to study the effect of the transverse temperature gradient along with the existing dead loads and live loads acting on the bridge superstructure. The bridge superstructure is modeled using SAP finite element based software. The results show that the temperature induced stresses are significant enough to cause crack in the bridge deck.

Keywords: Box Girder **B**ridges, Stress Reversal, Thermal Stresses.

1. INTRODUCTION

Bridge structures are subjected to continuous heating and cooling from the surrounding environment and solar radiation. This temperature variation causes the warmer portion to expand more than the cooler portion which induces thermal stresses in the bridge. In box girder bridges the temperature induced stresses are more severe due to the presence of a closed air cell inside the box section. Leonhardt [1] reported a case of damage of a prestressed concrete two-span continuous box girder Bridge (Fig. 1). Within five years of completion, large cracks (crack width > 5 mm) were observed along one web of the box section at which the web reinforcement reached the yield point. The damage was attributed to non uniform temperature variations.

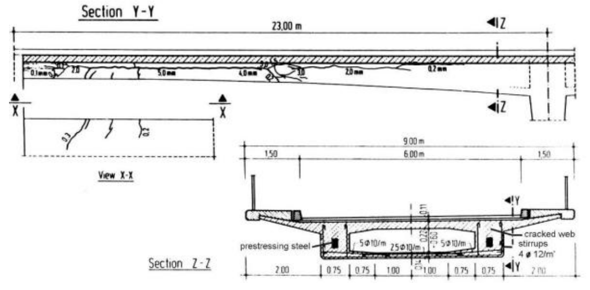

Fig 1. Longitudinal cracking in the webs of a continuous concrete box girder due to temperature effects [1]

Extensive research work has been conducted on concrete box girder bridges to identify the effect of temperature in these sections. A three dimensional finite element model of curved concrete box girder bridge has been developed by Ibrahim [2]. Several parameters such as time dependent temperature variations, geographic location, meteorological condition, convection and irradiation were considered in this model. It also considered some environmental boundary conditions such as diffuse radiation, bern radiation, reflected radiation and wind speed. Shaha, D [3] performed analytical research to investigate thermal effects on concrete bridges in the context of Bangladesh. Particular attention is given on the non-linear temperature variation over the cross section of concrete bridge decks and on the resulting longitudinal eigenstresses. Additional continuity stresses that develop in a continuous bridge are also addressed.

The Jamuna Bridge of Bangladesh which is the 12th longest bridge in the world consists of a concrete box girder section. The bridge established a strategic link between the eastern and western parts of Bangladesh. Extensive cracks have been reported at several locations of Jamuna Bridge [4]. Longitudinal cracks and transverse cracks are observed at top and bottom of the deck slab at several locations along the span of the bridge. Begum [5] has developed a computer program for calculating thermal stresses in transverse direction of box girder bridges. The program is built on the basis of flexibility method. This program can calculate thermal stresses of any arbitrary box section. The researcher used this program to calculate the temperature stresses in Jamuna

Multipurpose Bridge due to transverse temperature gradient. Begum [5] reported possible occurrences of thermal cracks in the deck slab and web of the section at several locations. However, this computer program can calculate the temperature effects only. Combined effect of temperature with the existing dead and live loads acting on the bridge were not included in this program.

2. OBJECTIVES AND SCOPE

The main objective of this study is to conduct a finite element analysis of the Jamuna Multipurpose Bridge of Bangladesh subjected to thermal loading along with the existing dead loads and live loads acting on the bridge superstructure. The bridge is modeled using SAP [6] finite element based software. Thermal loading is applied through transverse temperature gradient across the thickness of the deck slab. Longitudinal variation of temperature is not taken into account. Linear elastic material behavior is assumed in the analysis.

3. BRIDGE DESCRIPTION

The Jamuna bridge is slightly curved, about 4.8 km long, prestressed concrete box-girder type. It consists of 47 nearly equal spans of 99.375 m and 2 end spans of 64.6875 m. The main bridge is supported by twenty- one 3-pile piers and twenty-nine 2-pile piers. There are 128 m long road approach viaducts at both the ends of the main bridge. There are six hinges (expansion joints) that separate the main bridge structure into seven modules; two end modules, four 7-span modules and a 6-span module in the middle. The main bridge deck is a multi-span precast prestressed segmental structure constructed by balanced cantilever method (Fig. 2).

Fig 2. Balanced cantilever construction.

Each cantilever has 12 segments (each 4 m long), joined to a pier head unit (2 m long) at each pier and by an in-situ stitch at mid span. The deck is internally prestressed and of single box section. The cross-sectional characteristics and dimensional properties are shown in the Fig. 3 and 4. Parabolic variation of the depth of the box section is shown in the longitudinal elevation as in Fig. 5. The depth of box section has three variations in parameters. These are as follows:

1. Parabolic variation in depth (6.5m. at pier and 3.25 m. at mid span).
2. Parabolic variation in the thickness of bottom slab (0.65 meter at pier and 0.2 meter at mid span).
3. Parabolic variation in bottom slab width (6.4 meter at pier and 8.604 meter at mid span).

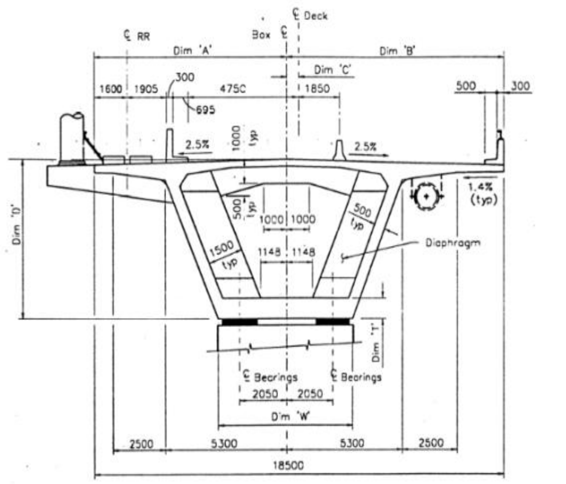

Fig 3. Typical deck section at pier (Source: Contract drawing of Jamuna Multipurpose Bridge Authority)

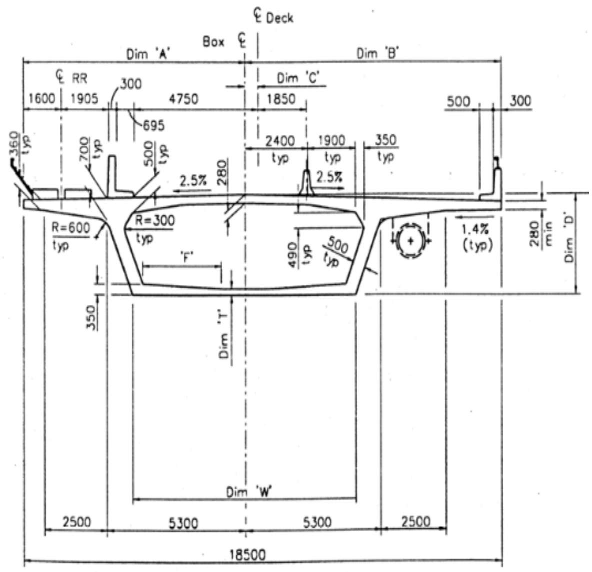

Fig 4. Typical deck section at mid-span (Source: Contract drawing of Jamuna Multipurpose Bridge Authority)

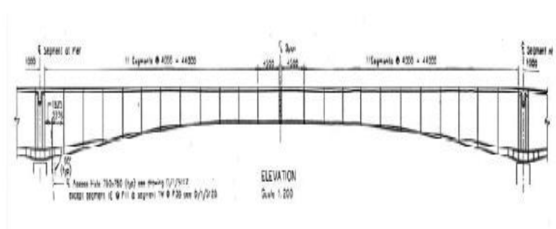

Fig 5. Longitudinal sectional elevation showing span geometry.

4. FINITE ELEMENT MODELLING

4.1 Element Selection

A typical span of the bridge is modeled using SAP [5] finite element based software. Four node three dimensional shell elements (Fig. 6) are used to model the bridge geometry. This element has six degrees of freedom per node: three translational and three rotational. The parabolic variation in depth and thickness of the box section is included in the finite element model.

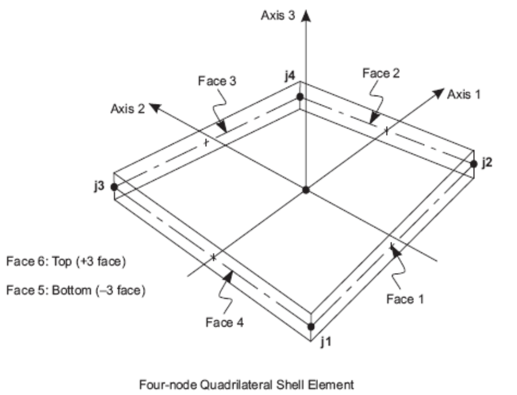

Fig 6. Shell element joint connectivity and face definition

4.2 Material Property

Linear elastic and isotropic material behavior is defined for concrete in the bridge deck. The values of the material parameters used in the finite element analysis are listed in Table 1.The prestressing forces in the reinforcing tendons are applied as initial conditions in the shell element.

Table 1: Material Properties for Concrete

Material Property	Value
E	32.02×10^3 (MPa)
ρ	2.356×10^{-6} (KN/m^3)
υ	0.20
α	1.08×10^{-6} ($^0C^{-1}$)
f_c'	45 MPa
f_t	2.8 MPa

4.3 Load Application

Temperature load creates thermal strain in the Shell element. This strain is given by the product of the material coefficient of thermal expansion and the temperature change of the element. All specified temperature loads represent a change in temperature from the unstressed state for a linear analysis, or from the previous temperature in a non linear analysis.

Bongobondhu Jamuna Multipurpose Bridge is stretching from Tangail to Serajgang. The temperature variation in that area is collected from the meterological data for that zone. A transverse temperature gradient develops across the thickness of the box section, due to the presence of the closed air cell inside the box. Two types of thermal gradient can develop as observed from the temperature variation in the surrounding environment. Highest temperature in that area is 43^0C, so temperature on the deck surface can be assumed as 43^0F and temperature inside the cell is assumed as 20^0C. This variation in temperature causes positive temperature gradient as shown in Fig. 7. After a few hours of hot weather temperature inside the cell will become close to the deck surface temperature. A sudden rain at this moment can result in a sudden drop in the outside temperature whereas the inside temperature remains constant (around 38^0C). This condition causes a negative thermal gradient across the thickness of the section (as shown in Fig 8).

In addition to thermal loading the bridge deck is subjected to dead loads (self weight of the bridge) and live load (i.e. truck loading). Effects of these loads on bridge superstructure are studied along with the transverse thermal loading. After the application of load a linear static analysis is performed in SAP and the results are analyzed for the three loading cases and as well as their combinations. A longitudinal profile of the finite element model showing the critical location of stress is shown in Fig. 9.

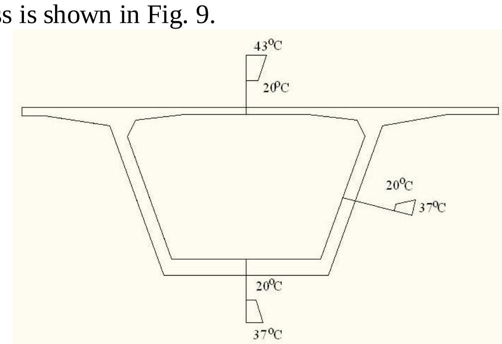

Fig 7. Positive temperature gradient on the bridge section.

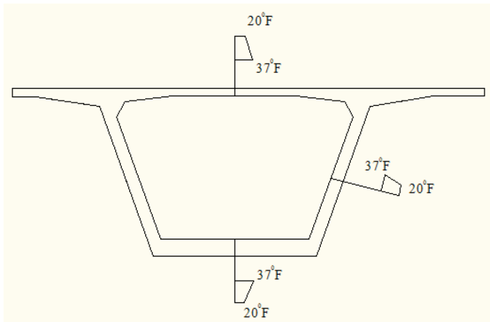

Fig 8. Negative temperature gradient on the bridge section.

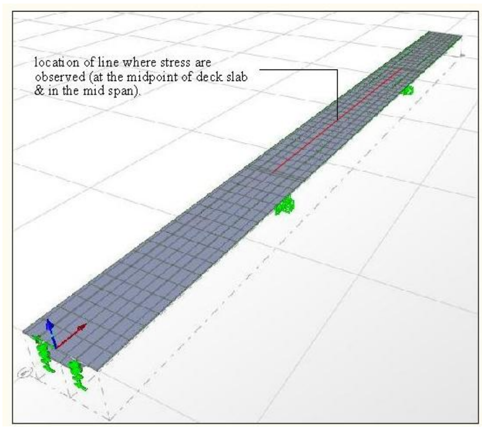

Fig 9. Finite element model for a continuous span of Jamuna bridge.

5. ANALYSIS OF RESULTS

The effects of the transverse thermal gradients along with the existing dead and live loads are studied by analyzing the stresses developed in the transverse and longitudinal directions of the bridge section. Figure 9 and 10 show the resulting stress contour in the bridge for positive and negative temperature gradients respectively. From these figures it is obvious that maximum tensile stress occurs at the top surface of the bridge deck slab for positive temperature gradient and at bottom of the deck slab for negative temperature gradient. Similar results were observed by the analysis using flexibility method for box girder sections as performed by Begum [4].

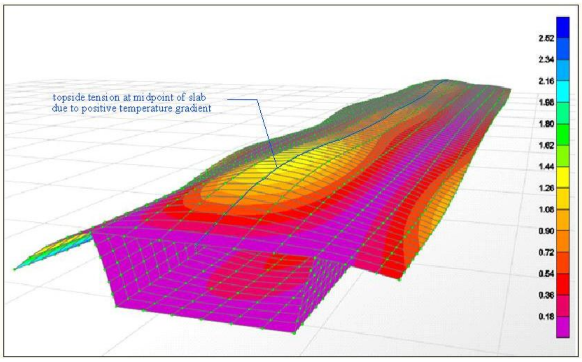

Fig 10. Stress contour for positive temperature gradient.

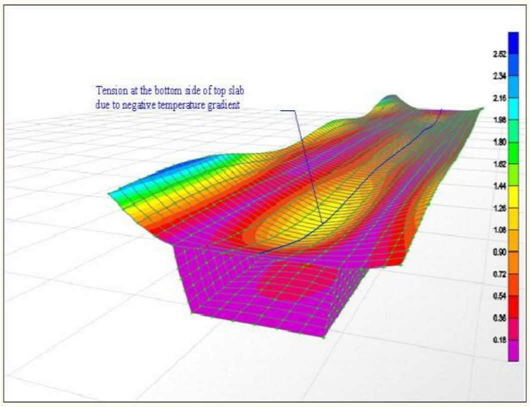

Fig 11. Stress contour for positive temperature gradient.

The variations of temperature induced stresses along the bridge span for the applied thermal gradients are shown in Fig. 12 and 13. The stress variations are plotted for dead load, live load, prestress forces & temperature gradient. The combined effect of all these loading conditions is shown as the resultant stress. The distribution of the transverse stresses along the bridge span for positive thermal gradients (as shown in Fig. 12) show that maximum transverse fiber stress at the center of the top slab is 3 MPa which exceeds the cracking stress for concrete. For negative thermal gradient the maximum tensile stress occurs at the bottom surface of the deck slab at mid span and is found to be 3.5 MPa (Fig. 13). From the analysis it is also observed that the stress at the junction of web and deck (Fig. 14) slab is 3 MPa which also exceeds the cracking stress limit for concrete.

These are the possible locations of temperature induced cracks in the Jamuna Bridge. The crack locations identified in this study match well with the actual crack locations observed in the bridge. It is confirmed from the analysis that crack may form in the initial stage prior to the wheel load in the bridge. So there is a possibility of early temperature crack in the bridge.

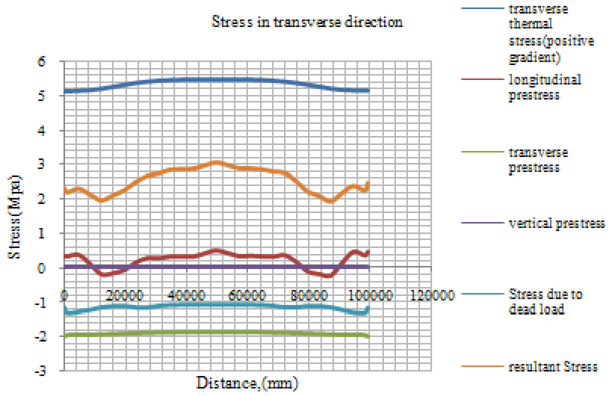

Fig 12. Transverse stress distribution along the span of the bridge for positive thermal gradient.

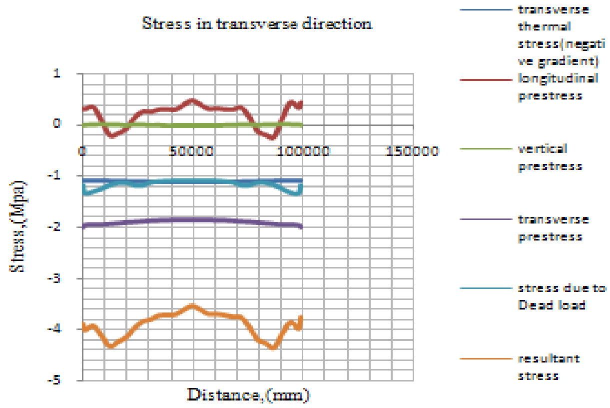

Fig 13. Transverse stress distribution along the span of the bridge for negative thermal gradient.

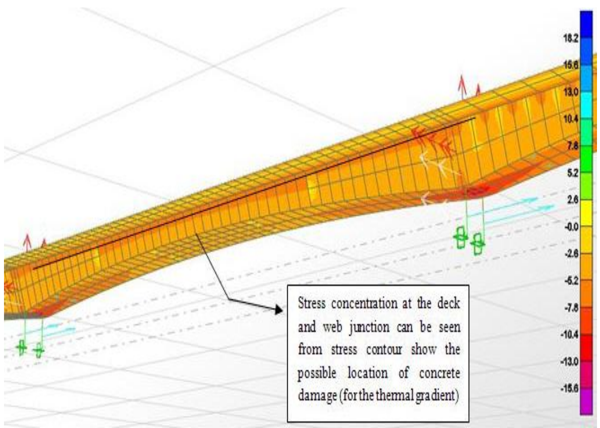

Fig 14. Stress concentration near web and deck joint.

From the analysis it is also clear that the bridge deck is subjected to reversal stress due to positive and negative temperature gradient. This case happens when a sudden rain occurs in a hot summer day.

6. CONCLUSIONS

The effect of transverse temperature gradient on Bongobondhu Jamuna Multipurpose Bridge of Bangladesh is studied through finite element analysis. Transverse temperature gradients were applied across the thickness of the deck slab. The effects of the thermal gradient along with the existing loads were studied by plotting the transverse and longitudinal stresses at various locations of the cross-section. The results showed that the temperature induced stresses in the bridge can be significant enough to cause crack in the bridge deck. Potential crack locations were also identified. Reversal of stresses was observed to occur in the bridge deck due to cyclic positive and negative thermal gradient over a day. This reversal of stress can cause severe degradation of the mechanical properties of concrete with time and therefore may reduce the life of this bridge structure if proper measures are not taken.

7. REFERENCES

1. Leonhardt, F., Kolbe, G., and Peter, J., 1975, “Temperature Differences Endanger Prestress Concrete Bridges,” Berlin, V.60, pp.231-244.
2. Ibrahim, M.M.A ,1995, “Three Dimensional Thermal Analysis of Curved Concrete Box Girder Bridges”. M.Sc Engineering Thesis, Concordia University, Canada.
3. Saha, D. ,1997, “Finite Element Analysis of Temperature Effects in Concrete Bridge Decks”. M.Sc. Engineering Thesis Bangladesh University of Engineering & Technology, Dhaka, Bangladesh
4. Amanat, K.M., Amin, A.F.M.S., Hossain, T.R., Kabir, A. & Rouf, M.A. , 2010, “Cracks in the box girders of Bongobondhu Jamuna Multipurpose Bridge-Identification of causes based on FE analysis”. *Proceedings of IABSE-JSCE Joint Conference on Advances in Bridge Engineering-II,* Dhaka, Bangladesh.
5. Begum, M. , 1999, “Analysis of thermal stresses in the Box Girder Bridges”. B.Sc. Engineering Thesis, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.
6. SAP 2000 Documentation.

8. NOMENCLATURE

Symbol	Meaning	Unit
E	Modulus of Elasticity	MPa
ρ	Density	KN/m^3
υ	Poisson’s ratio	unitless
α	Co-efficient of thermal expansion	$^0C^{-1}$
f_c'	Compressive strength of concrete	MPa
f_t	Cracking stress of concrete	MPa

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