"Effect of Temperature Stresses in Composite Girder Bridges"

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Abstract: **- Thermal actions differ from other load types considered during bridge design through being a constraining load. A temperature profile can be divided into a uniform part that affect the bridge with a linear expansion and a non-uniform part that will induce an arch shape of the bridge deck.**

The response of composite bridge structures to environmental temperature effects is a complex transient phenomenon as bridges are subjected to daily repeated cycles of solar heating and cooling and ambient temperatures varying with time.

Composite bridges exposed to environment continuously undergo varying temperatures due to diurnal and seasonal changes in climatic or atmospheric conditions. Temperature distributions in a bridge structure depend upon several environments, meteorological and a bridge parameter. The major environmental parameters influencing the temperature distributions in a bridge structure include intensity of solar radiation, daily range of ambient air temperature humidity, cloud covers, wind speed, turbidity of atmosphere etc.

In addition to these parameters the temperature variation in bridges is also affected by some other parameters as well which includes geographic location of the bridge as governed by the latitude and altitude, geometrical parameters and materials properties of the bridge cross sections.

Diurnal and seasonal changes in the local climatic conditions cause the rise and fall in the overall temperature of a bridge structure, referred to as effective bridge temperature, and development of temperature differentials across the depth of cross section referred to as thermal gradient or differential temperature. The range of the daily maximum and minimum ambient air temperature usually affects the effective temperature of the bridge while the solar radiation contributes to the thermal gradients in the bridge cross sections.

The objective of the study were to construct and instrument composite bridge, b) to subject the structure to thermal loading, and c) to correlate the experimental temperature distributions. It was concluded that theoretical procedure provides a rational method for predicting the thermal behavior of composite-girder bridge structures and can be applied with reasonable confidence when used with realistic temperature, profiles, material properties, and substructure stiffness characteristics.

I. INTRODUCTION

One of the characteristic features of the steel-concrete composite bridges is a two-stage process of their erection. In the first phase loads which are transferred by steel girders appropriately to the static scheme compatible with the construction method. After the erection of the bridge deck loads are transferred by steel-concrete composite cross section.

The period between two phases is a period of curing of concrete slab. In this period a series of chemical and physical processes are there, among which the process of emission of cement heat of hydration is very important. Due to the emission of cement heat of hydration in erected composite cross-sections an additional thermal load occurs. During the impact of the cement heat of hydration and the ambient temperature in erected composite cross-sections arises the temperature difference is caused by large differences in thermal inertia of steel and concrete. The temperature differences induce an additional stresses in concrete slab and steel beams.

The complexity of the stresses consist in the necessity of taking into account the changes in mechanical properties and strength of the curing concrete (e.g. modulus of elasticity, compressive and tensile strength). The strength characteristics of the composite cross section depend on the time. The cross-sectional area, the moment of inertia and the position of the center of gravity of the cross-section depends on changing in time modulus of elasticity of the curing concrete.(Flaga 2001).

The nonlinear temperature distributions arise in bridge structures lead to structural behavior problems. Thermal effects in composite bridges are associated with the distress in the superstructure. Temperature difference causes damage to the structure. The distress in composite bridges is due to ignorance of the effect of thermal gradients that set in due to change in climatic conditions. With the advancement in bridge engineering use of continuous span is of utmost importance to lay down the basis of design for temperature effects (Mirambell and Agaudo, 1990)

Bridge structures exposed to environmental thermal actions like solar radiation, ambient air temperature, wind speed, location etc continuously undergo varying temperatures. The temperature developed in bridge structures is due to various effects like solar radiation, convective, radiative heat transfer to and from the atmosphere and the heat of hydration. This interaction with air temperature and solarradiation leads to daily and seasonal changes in the temperature of the composite bridge structure. A steel-concrete bridge gains and loses heat from the solar radiation, and convect to and from the atmosphere. Temperature variation is induced depending upon the geometry, location, orientation of bridge, climatological conditions, and thermal properties of the bridge material and surfaces which are exposed and is also affected by cloudiness, turbidity of atmosphere and wind conditions. In day time there is rise in temperature and at night temperature is less and as a result temperature difference is developed. Solar radiation is partly absorbed and partly reflected on the composite bridge surface. Absorbed energy heats the surface and temperature rise is there throughout composite bridge and radiation radiation absorbed also depends upon the nature and colour of the top surface of bridge. Seasonal variation contributes to the non linear thermal gradients in the bridge cross section. The maximum and minimum ambient air temperatures usually affect the temperature of the bridge while solar radiation contributes to temperature difference in bridge crosssection. The temperature difference produce stress which vary with time across the cross section of the composite bridge. Variation in temperature causes bridge to expand and contract when unrestrained. But when it is restrained thermal stresses developed which may distress bridge superstructure if it is not accounted in the design.

There are two types of stresses caused by non linear temperature gradients tensile stresses in central part of depth and and compressive stresses in top fibres of the deck. While reverse occur in night. The tensile stress when added to stresses from other loading conditions may be high enough to cause cracking (Elbadry and Ghali, 1986). Temperature stresses depend largely on the temperature gradients across a bridge cross section and are enough to damage parts of composite bridge.

The thermal effects should be considered for serviceability limit state conditions in the process of the bridge design.(Clark,1983, Branco and Mendes, 1993). The damage in composite bridge indicate that temperature effect is very important and should be considered while designing the bridge superstructure for different loading conditions.

II. CONSTRUCTION MODEL OF BRIDGE

The thickness of the composite concrete deck slab on deck type bridges typically will be 250mm. An in-situ slab of this thickness, cast either on timber formwork or permanent formwork, will span around 3.5m, hence girder spacing (main girders in multi-girder decks, cross girders in ladder deck systems) will typically be at 3.5m centres, or a little more as the slab spans between the flange outstands. Generally contractors like to use permanent formwork rather than conventional timber formwork. Use of proprietary parapet cantilever formwork systems is now widespread for the deck slab cantilevers. Cantilever length is usually not more than half the girder spacing on multi-girder decks, typically 1.5m. The designer needs to consider how the steelwork system and deck slab are arranged geometrically to accommodate crossfall and superelevation, and whether to split dual carriageway underbridge decks down the middle.

III. EXPERIMENTAL INVESTIGATION ON THERMAL EFFECTS

The study carries out an experimental investigation to determine the temperature distributions in a concrete bridge girder due to solar radiation, ambient air temperature, and wind speed. Since composite concrete girders have commonly been designed this study chose an Jaipur for the cross-section of a test girder. The length of the test girder was designed to be five feet since temperature distributions were assumed to be constant in the longitudinal direction. The experiment was conducted during the months of April 2017 to March 2018 in the east-west direction so that only the top surface and one side of the girder received direct solar radiation from the sun. This orientation would provide the girder with extremes in transverse temperature distributions.

IV. FINITE ELEMENT MODEL

Finite-element models of the Jaipur Bridges were developed using the finite-element software ‘ANSYS’ (Computers and Structures, Inc.). These models were validated using changes in strain from a live-load test in the case of the Jaipur Bridge.

The finite-element model was divided into five principal sections: concrete deck, bottom flange, concrete girders, diaphragms and parapets. Each of these bridge sections was modeled using eight node, hexahedral solid elements, except at the diaphragms and skewed end of the bridge where occasionally six nodal triangular solid elements were used due to the bridge geometry.

V. FACTORS THAT AFFECTS TEMPERATURE DISTRIBUTION IN COMPOSITE BRIDGE STRUCTURE

All structures are affected by its surrounding temperature. Temperature can cause stresses in two ways, either by a non linear temperature distribution causing eigenstresses or a constraint restricting the structure from moving free. The thermal loads can be divided into a number of factors.

Variations of temperature is due to heat of hydration of fresh concrete. The temperature rise by the chemical process depends on the type and amount of cement, on the thickness of the concrete member, on the thermal insulation of the forms and on the temperature of the mixing water and surrounding air. A temperature rise of 30°C to 50°C can be expected in members greater than about 0.50 m due to this source of heat.

Also, composite bridge is continuously losing and gaining heat viz from solar radiation, radiation to or from the sky or surrounding objects, and convection to or from the surrounding atmosphere. Temperature changes induced by these sources depend upon the geometry of the bridge cross section and various factors:

i. Geographie location of the bridge ie latitude and altitude.

ii. Orientation of the bridge axis with respect to the sun.
iii. Time of the day and season.
iv. Degree of cloudiness and turbidity of the atmosphere.
v. Climatological conditions: expressed in terms of the diurnal variations of the ambient temperature and wind speed.
vi. Nature and colour of bridge deck surfaces: expressed in terms of solar radiation absorptivlty, emissivity and surface convection coefficient.
vii. Thermal and physical properties of the constituent materials of the bridge: thermal conductivity, specific heat and density

In the daytime during the summer, the heat gain is greater than the heat loss, resulting in a temperature rise throughout the cross section. During a winter night, the converse is true, and the temperature in the superstructure drops. Radiant energy from the sun is partially reflected and partially absorbed. Reflected energy does not influence bridge tem perature; absorbed energy, however, heats the bridge deck surface and gives rise to a temperature gradient through the deck. The amount of radiation absorbed by a bridge deck is a function of the nature and colour of the surface. A dark, rough surface has higher absorptivity than does a light, smooth surface and consequently absorbs more solar radiation. Some of the absorbed radiant energy is lost from the surface by convection and re radiation. Convective heat transfer from or to the atmosphere is a function of wind velocity, ambient air temperature, and deck surface temperature.(Elbadry and Ghali, IABSE, 1983)

VI. EFFECTS OF BRIDGE TEMPERATURE

Two types of temperature effects are considered in bridge design; uniform temperature change and nonlinear thermal gradients. A uniform temperature change causes longitudinal expansion while a nonlinear thermal gradient cause longitudinal expansion and vertical curvature.

Nonlinear thermal gradients became a consideration in bridge design when composite bridge superstructures began to experience cracking in the bottom slab of the composite girder .The cracks were observed to expand and contract over the course of the daily heating cycle. The damage to the bridges demonstrated the need to understand and design for nonuniform temperature.

The uniform temperature component in the bridge is an evenly distributed temperature that will cause the full bridge to expand or contract. These movements will give rise to stresses in the structure if it is constrained to move. A recommendation of the temperatures to be used have been stated, these bridge temperatures depends on the minimum and maximum shade air temperatures where the structure is erected.

Seasonal temperature variations over the course of the year uniformly increase or decrease the temperature of the bridge, causing a proportional increase or decrease in the length of the bridge. A nonlinear temperature distribution throughout the depth of the bridge superstructure is caused by the daily fluctuations in solar radiation and ambient air temperature. This nonlinear temperature distribution is classified in two categories, positive thermal gradients and negative thermal gradients.

Positive thermal gradients occur when the temperature of the deck of the bridge is higher than the temperature of the girders. The positive gradient is a result of the rapid heating of the deck due to short wave solar radiation absorbed into the top surface along with the slow spread of heat through the depth of the bridge. Positive thermal gradients are typically observed during summer afternoons. The yearly maximum positive thermal gradient occurs on days with high solar radiation and low ambient temperatures during the summer.

Negative thermal gradients occur when the deck surface temperature is lower than the web temperature. The negative gradient typically occurs when the long wave radiation leaving the deck surface during the night rapidly cools the top of the bridge but cools through the web more slowly. Maximum negative thermal gradients occur in the early morning hours of winter. Negative thermal gradients have a significantly lower temperature difference than positive thermal gradients and do not cause tension in the soffit. Since negative gradients are not responsible for soffit cracking, design considerations are not affected by negative thermal gradients.

VII. DESIGN OF THERMAL GRADIENTS

Thermal gradients that develop depend on the site specific environmental conditions. The solar radiation and fluctuations of air temperature vary greatly throughout the year and across the nation. American Association of State Highway and Transportation Officials (AASHTO) broadly summarizes the variations across the United States by dividing the country into four zones (based on solar radiation patterns) with a thermal gradient assigned to each zone. Prior research has been conducted to investigate the appropriateness of the assigned thermal gradients in the first three zones. However, the location of the previous Zone 1 verification studies may not adequately reflect the climate of the southern portion of Zone 1.

The thermal gradient through the depth of the bridge causes internal stresses and associated forces in the supports. The resultant stresses from the thermal gradient are divided into two components; primary thermal stresses and secondary thermal stresses (Priestley and Buckle, 1978).

Primary thermal stresses (which develop in a determinate structure or a structure with internal redundancies removed) are the results of nonlinear thermal gradients causing linear expansion through the depth of the beam. The final strain profile of the beam is assumed to be linear. The free strain profile is thermal strain at each point of the cross section if expansion were completely unrestrained in each fiber. The difference between the final strain and the free strain profiles cause self-equilibrating primary stresses. In an indeterminate bridge the vertical deflection is restrained creating bending moments which cause secondary thermal stresses. The forces restraining the vertical deflection of a bridge caused by curvature also influence the bridge support reactions. The forces in the bearings that connect the superstructure to the substructure change as the bridge heats and cools in a diurnal cycle. Modern technology allows for long term collection of meteorological data with small time intervals unlike prior research which limited meteorological data to use in heat flow. Heat flow equations have been used to predict nonuniform temperature distribution in a bridge over time with applied boundary conditions representing the solar radiation, ambient temperature and wind speed. The heat flow equation predicted how heat traveled from the top of the cross section down through the depth; the solar radiation heats the surface of the deck, while ambient temperature and wind drew heat from the bottom of the superstructure. Design gradients described the most extreme temperature variation.

The Road Research Unit Bulletin of New Zealand (Priestley and Buckle, 1978) further offered a method to convert the thermal gradient into internal stresses that vary through the superstructure depth. The soffit was considered the critical section of design as case studies showed it experienced the most damage from thermal gradient. Damage to the soffit was a result of service (normal daily operation) loading rather than an extreme event (large loads of infrequent occurrence). Five bridges instrumented to record temperature were compared to the fifth order design gradient. The collected temperature profiles were similar in shape to the estimated fifth order gradient which led to the conclusion that the design gradient was conservative when predicting temperature through the cross-section depth (Priestley and Buckle, 1978).

VIII. REVIEW OF CODES FOR THERMAL EFFECTS

The origin of thermal loads is a combination of heat transfer processes, material properties and climate variations. Based on these basics, building codes have been developed throughout the years to set up certain regulations and recommendations. How thermal actions and crack width calculations are treated in the code is included. In Sweden, the main building code for the design of bridges is Eurocode. In addition, the main client of bridges in Sweden, Trafikverket, has their own code documents complementing the Eurocode .

The codes of practice of different countries for the design of concrete bridges provide many different approaches for the thermal effects. A summary of provisions in international design codes for temperature effects in bridges has been presented by some researchers viz(Imbsen et al; 1985, Branco and Mendes, 1993, Priestly and Thurston,1975). The basic difference in various codes is related to consideration of the type of thermal loadings, meteorological parameters at the places where the bridge is to be constructed, methods adopted to accomodate these thermal loadings in the design of bridge structures. Most of the codes has given following things:

i. Present provisions in all the codes are related to effective mean temperature and most of them specify temperature gradients.
ii. Design mean temperature are defined are defined with two extreme values .
iii. Vertical temperature gradients , non linear temperature distribution but in some cases horizontal.
iv. Indian codes are IRC:6-2000, IRS- 1997 etc.
v. AASHTO bridge code -2000
vi. Uniform temperature components.
vii. EURO Code -4

IX. PRESENT STATUS OF RESEARCH AND FUTURE SCOPE OF THE WORK

Various research studies have been carried out to determine what should be the design temperature gradients to be considered for a tropical country like India.

IRC:6-2000 suggested to assume positive and reverse temperature difference for the purpose of design, which is similar to recommended by the International codes.

Indian Railway Standards for concrete bridge code 1997 specifies that depending upon environmental conditions linear temperature varies in the composite bridges.

Due to absence of detailed provisions in national codes bridge designers are adopting the practices of BS code and presently EURO Code is greatly followed. However applicability of these codes is yet to be established in Indian Context. Therefore there is urgent need of research to study thermal effects to be considered in the design of concrete bridges.

X. CONCLUSION

With the FEM theory, a plane model is built to simulate temperature effect of composite bridge under solar radiation. Computation and analysis on temperature field show that the temperature distribution of composite bridge is complex, with a tendency to be high in the outside and low inside. From the temperature distribution of composite bridge, Changes in temperature of the top plate are the most severe, followed by web-plate, and the bottom slab least.

Computation results on temperature stress show that the highest tensile stress along the breadth direction of the section is produced at the bottom edge of top plate; the highest tensile stress along the height direction of the section is produced at the inner side of the web plate; the highest tensile stress along the length direction of the bridge is produced at the inter section of web plate and top plate.

Therefore, considerable temperature stress will be produced in the composite bridge under solar radiation, which is higher than the tensile strength of concrete. So in the design of composite bridge, great attention should be paid to the temperature stress under solar radiation. Considerable temperature reinforcement should be added.

XI. RECOMMENDATION FOR FUTURE RESEARCH

1. In depth non linear analysis of composite bridge needs to be explored further by detailed parametric studies.
2. A study of the thermal behavior of the concrete deck in the transverse and vertical directions.
3. A study of the effect of diaphragms and supports on transverse action.
4. A determination of the effect of noncomposite areas on deck stringer thermal interface forces and stress variations.
5. The effect of slab reinforcing on the transfer of heat through a concrete bridge deck, i.e., temperature distribution should be studied.

REFERENCES

[1]. Dwivedi , A.K. Bhargava , P. Bhandari, N.M.(2004), " Thermal Gradients in Concrete Box Girder Bridges", The Bridge and Structural Engineer, IABSE, New Delhi Vol 34, No 1, pp 53-72

[2]. AASHTO(1989) , " Guide specifications for Thermal effects in Concrete Bridge Superstructure", Washington, D.C.

[3]. Bhandari , N.M. and Bhargava , P(2002), " Thermal Studies in Concrete Bridges" Volume on Bridge Engineering. Some Issues of Research Interest, Department of Civil Engineering , Indian Institute of Technology, Roorkee, India pp 109-130.

[4]. Branco, Fernando A and Mendes, Pedro A(1993), " Thermal Actions for Concrete Bridge Design", Journal of Structural Division, ASCE, Vol 119, No 8,pp. 2313-2331

[5]. British Standard Institution, BS 5400-1978: Part 2: Steel, Concrete and Composite Bridges, " Specification for Loads", London.

[6]. Clark, L.A.(1983), " Concrete Bridge Design to BS 5400", Construction Press, London, pp 36-38 and 158-170.

[7]. Elbadry, M.M. and Ghali A (1983), " Temperature Variations in Concrete Bridges", Journal of Structural Division, ASCE Vol 109, No STIO, pp 2355-2374.

[8]. Imbsen, R.A, Vendershaf, D.E, Schamber, R.A and Nutt, R.V(1985), " Thermal Effects in Concrete Bridge Superstructure", Report No 276, Transportation Research Board(TRB), National Cooperative Highway Research , Washington, D.C.

[9]. Priestly, M.J.N(1978), " Design of Concrete Bridges for Temperature Gradients", ACI Journal , pp: 209-217

[10]. Flaga (2001) "Application of Composite Structures in Bridge Engineering. " Civil And Environmental Engineering Reports, Volume 15, Issue 4, pp.57-8

[11]. Mirambell and Agaudo,(1990) "Temperature and Stress Distributions in Concrete Box Girder Bridges" Journal of structural Engineering Volume 116 Issue-9 September 1990