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TEMPERATURE STRESSES EFFECT IN COMPOSITE GIRDER BRIDGES LOCATED AT JAIPUR IN RAJASTHAN

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ABSTRACT

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

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

The aim of the study is to construct and instrument composite bridge, b) to subject the structure to thermal loading, and c) to correlate the experimental temperature distributions. Theoretical procedure provides a rational method for predicting the thermal behavior of composite-girder bridge structures and it can be applied when used with realistic temperature , profiles, material properties, and substructure stiffness characteristics.

Bridge structures are subject to complex thermal stresses which are varying continuously with time. The magnitude of these stresses depends upon the temperature variation within the structure and this also depends upon the geographic location and the orientation of the bridge, climatological conditions, geometry of cross section and thermal properties of the material and the exposed surfaces. Many bridge designers recognize that the temperature variations can produce high stresses with little guidance is given in bridge design codes on how these stresses can be accurately calculated. The distribution of temperature throughout the cross section of a bridge structure must be known if the resulting stresses, reactions and deformations are to be calculated. Analysis of temperature distribution throughout the cross section of a typical bridge structure is complex as temperature varies with time and also varies from section to section. In a concrete bridge with constant cross-sectional properties over a long length, it is assumed that the temperature is constant over the bridge length and varies through the depth and within the width of the cross section. Therefore, the temperature field to be determined at any time t is two-dimensional. In this paper, a method of analysis based on finite elements is described to determine the time-dependent temperature variation within the cross section of a concrete bridge of arbitrary geometry and orientation for a given geographic location and environmental conditions. The finite element formulation for the analysis of transient heat flow in a two-dimensional body is treated by various authors.

In simply supported bridge linearly or uniform varying temperatures across the depth of bridge cross section produce no stresses but the bridge is subjected to self equilibrating stresses due to non linear temperature gradients because of the restraint of thermal expansion that would occur between the different fibers.

In continuous bridges, stresses of continuity are developed over the supports due to restraint of induced thermal curvature which is added to self equilibrating stresses to get the total state of thermal stresses. Non Scientific research studies have been carried out to calculate what should be the design of thermal gradients.

The bridge designers are adopting British Code, BS 5400; 1978, IRC :6-2000 and Indian Railway Standards, IRS-1997 have also recommended temperature gradients to be considered in the design.

The Heat Transfer analysis is used in solving the temperature field distribution. The analysis process should have two steps. The first step is to solve the composite girder internal temperature field distribution and determining boundary conditions. After calculating the temperature field, effect of thermal stress study is done.

A study related to thermal stresses has been carried out with 2 D and 3 D approach which shows significant change in thermal stresses for varying span length in a simply supported bridge.

A computer program on finite element method has been developed in ANSYS to study the thermal effects in composite girder bridges.

This study is carried out to predict the temperature distribution and thermal response of a composite girder bridge located in different parts of country in three seasons ie winter, spring, summer respectively. The country is divided into 22 zones and it was seen that many zones computed value of thermal gradients and the observed values of the corresponding stresses differ minutely.

The numerical implementation suggested the adequacy of classifying into seven zones and attempt has been made to put thermal design recommendations for each zone.

To do this one city from each zone has been considered as the respective representative city to predict the thermal response of a composite girder bridge.

A detailed parametric study has been carried out to determine the thermal gradients and induce stresses in composite bridge due to variations in environmental, geometrical and materials parameters for one location ie Jaipur, the capital of Rajasthan which can be repeated if necessary for the other zones.

Some aspects of study include:

a) Effect of the environmental parameters i.e. ambient air temperature, wind speed and turbidity factor.

b) Effect of bridge orientation.

c) Effect of geometrical parameters eg shapes of the cross section, variation in top concrete deck thickness, steel girder web thickness and total depth of the cross section.

d) Effect of the material parameters like wearing coat of asphalt concrete over the top deck, percentage of steel in concrete sections, modulus of elasticity and coefficient of thermal expansion of steel and concrete.

It has been seen that non linear thermal gradients and induced stresses in a composite girder bridge are maximum when the range of daily maximum and minimum ambient air temperature is large, the turbidity of the atmosphere is low, the surrounding wind speed is minimum and the top deck is covered with a thicker of asphalt concrete.

KEYWORDS :

INTRODUCTION TO RESEARCH WORK

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 solar radiation leads to daily and seasonal changes in the temperature of the composite bridge structure. A steel-concrete bridge gains and losses 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 color 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 cross-section. 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.

Literature Review

Steel and steel-concrete composite bridges have been the subject of investigations, reported in the literature, is the design and structural behavior of the bridges. The investigations are the research papers presenting laboratory tests on the bridges and their components, limited full-scale tests on the bridge components, and numerous numerical and analytic investigations of the bridges and their components. The investigations covered different types of bridges subjected to different loads and designed according to rules specified in current codes of practice.

Temperature effects on bridges can be classified into effects resulting from the seasonal and/or diurnal variation in the mean bridge temperatures and effects resulting from the variation in temperature between different elements of the bridge at any point in time. Variations in the mean bridge temperature result in the expansion or contraction of an unrestrained bridge superstructure. Thermally induced stress will result if the superstructure is fully or partially restrained by its supporting columns, piers, or abutments. The variation in temperature between elements of the bridge will result in translational as well as rotational distortions of the superstructure. Rotational distortions caused by a variation in temperature through the depth of the superstructure will cause bending moments in a structure which is continuous over more than one supports. When the temperature variation is nonlinear with depth, stresses will also be induced because of the tendency for plane sections to remain plane. Most of the bridges have been designed to accommodate the longitudinal movement resulting from temperature strain. But with the recent changes in bridges types, it has become apparent that temperature differentials also exist in bridge superstructures. These temperature differences cause stresses that should be included in the procedures of design. The current AASHTO specifications include temperature ranges of mean temperature conditions that affect contraction and expansion of concrete bridge superstructures, there is no recommendation for temperature differentials that occur in superstructure sections.

Many bridge design guidelines and specifications recognize the temperature gradients throughout the depth of a bridge superstructure and recommend that vertical temperature gradients is to be considered in the design procedure. Apart from these , some guidelines have also recommended that temperature gradients be used in the transverse direction to reflect the temperature changes that occur between the internal and external surfaces of composite girder bridges. The thermal response of a bridge involves a combination of the temperature, the intensity of solar radiation, the absorptivity of the materials of structures, and the depth of the superstructure. Although many researchers recognize these factors and have proposed various design specifications that include these thermal effects, they often disagree about the importance that should be included in the design procedure.

Heat transfer by radiation is generally considered to be the very important of the three mechanisms. During the daylight hours when the structure is exposed to the sun, especially during the warm summer months, a net gain of heat energy is there through the depth of structure, primarily as a result of the solar radiation impinging on the surfaces of the structures. Conversely, primarily because of the result of reradiation to the surrounding environment of the heat energy stored in the structure, a net loss of heat energy occurs during the night. During the summer, the temperature in the surface of the top of the bridge deck is warmer than the soffit, which results in a positive gradient. Negative is the intensity of the solar radiation reaching the surface of a bridge which is dependent on several other factors, each pertaining to the condition of the earth's atmosphere. The intensity of solar radiation varies daily. Because of the poor thermal conductivity of concrete, these diurnal variations result in temperature gradients within bridge superstructures. The radiation which penetrates the atmosphere and reaches the surface of a bridge deck has two effects. It may penetrate or may reflect the surface, be absorbed and converted to heat. The amount of absorbed radiation is dependent on the type of surfacing of the bridge. Various media absorb different quantities of radiation. Colored bodies are differentiated by their selective absorption of different wavelengths of light. A body which absorbs all wavelengths is known as a "blackbody." Concrete structures function as "gray bodies" because they absorb amount of wavelength and reflect the remainder wavelength.

Emerson has investigated the amount of radiation absorbed on bridges having various amounts of surfacing. Emerson concluded that the influence of the depth of deck surfacing should also include the shape of the cross section. Priestley investigated the effects of white surfacing, black surfacing, and no surfacing on a one-quarter scale model of a box girder bridge. The maximum surface temperatures of the concrete were found when the deck was unsurfaced. The white surfacing was found to yield the lowest temperatures. The temperatures yielded by the black surface were about 10 percent lower than those occurring in the unsurfaced concrete. This difference was because of the insulating effect of the top, black layer, and it had a greater absorptivity of radiation than the base concrete surface.

In addition to heat transfer by conduction and convection also takes place at the structure surface. It is difficult to assess the heat transfer by conduction because it is small. It is normal to allow for heat transfer by conduction and convection by assuming a single, combined coefficient sensitive to wind velocity, ambient air temperature, and surface temperature.

After the variables governing the heat exchange have been defined and quantified the surface boundary conditions is developed and the temperature distribution throughout the structure is calculated. Researchers have developed various expressions for the heat-energy exchange at the surface of a structure to help the bridge designer establish boundary conditions.

The temperatures within the structure may be determined after establishing parameters governing the heat exchange at the boundaries of a bridge. A bridge superstructure is gaining and losing heat which produces both seasonal and diurnal variations in the bridge, variations that are of concern to the bridge designer. Seasonal variations provisions are included in the design of bearings, hinge seats, and substructure components that are connected to the superstructure. The mean temperature of the superstructure is used in this case.

The main objective of the investigations is to satisfy safety and serviceability requirements imposed by design codes of practice and also to fulfill other requirements such as cost, self-weight, and aesthetic appearance.

Model of Finite Element

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

The finite-element model is divided into five principal sections: bottom flange, concrete decks, concrete girders, diaphragms and parapets. Bridge sections were modeled using eight node, hexahedral solid elements, except at the skewed end of bridge and diaphgrams where six nodal triangular solid elements were used due to the bridge geometry. ANSYS is a finite element analysis program used for solid modeling. It has capabilities in thermal, and structural analysis. The solid model consists of nodes or key points, lines, areas and volumes with increasing complexity in that order. Suitable ideas need to be put into the model before building the entire model. Once the model is meshed, volumes, areas, or lines cannot be deleted if they are connected to existing meshed elements. The aspect ratio and type of mesh is decided depending on the size and shape of the complete solid model.

Model and Instrument Program

The thickness of the composite bridges typically is 250mm. An in-situ slab of this thickness, cast either on timber formwork or permanent formwork, will span around 3.5m, hence girder spacing will typically be at 3.5m centers, or a little more as the slab spans between the flange outstands. Generally permanent formwork is liked by the contractor rather than conventional timber formwork. Use of cantilever formwork systems is now widespread for the deck slab cantilevers. Cantilever length is not more than half the girder spacing on composite girder decks, typically 1.5m. The designer needs to consider how the steelwork system and deck slab are arranged geometrically to accommodate cross fall and super elevation, and whether to split dual carriageway under bridge decks down the middle.

The study carries out an experimental examining to determine the temperature distributions in a composite 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.

Distributions for the steel bottom flange the temperature do not vary very significantly in the transverse direction under summer conditions. Under winter conditions measured temperatures on the south facing web were higher than the north facing web during day time. This difference between two webs induces thermal curvature in the cross section of composite bridge.

For the concrete deck temperature does not vary significantly in concrete deck along transverse direction.

Model Validation

Two sets of experimental data for temperature distribution in composite girder section temperature data for an bridge at Jaipur have been employed to validate the proposed FE model for the prediction of temperature profiles. The temperature distributions are numerically predicted for the cross section of the bridge model that has been instrumented to measure temperature at various locations of the composite girder bridge.

Environmental Variables

Temperature behavior in composite bridge is caused by both short-term which is daily and long-term which are seasonal environmental changes. Seasonal fluctuations of environment from winter to summer, or vice versa, will cause large expansion and contraction. If the bridge is free to expand longitudinally the seasonal change will not lead to temperature induced stresses. However, daily changes of the environment result in a temperature gradient over the bridge cross section that causes temperature caused stresses. The magnitude of these stresses depends on the temperature gradient of non linear form and the flexural indeterminacy of the bridge. Past research have been carried out in this area and indicates that the significant environmental variables which influence the temperature distribution are solar radiation, ambient air temperature and wind speed.

Parametric Study of Jaipur Bridge

In the present work parametric study has been carried out for the jaipur region and also for six suggested zones in India as suggested by Dr A.K.Dwivedi.

a) Critical temperature stresses for different zones.
b) Modification factors for different cross sectional geometrics.

The varying cross sectional shapes and corresponding stresses are given for the six zones.The critical temperature stresses and proposed modifications factors are presented.

The case study carried out for Jaipur Bridge shows that strain values obtained from analytical results are quite to what that was found analytically. The small variations may be attributed to varying thickness of the deck.

Further one may require incorporating the partial restrained support conditions in the bridge model to account for the actual site conditions. The temperature variations across the web thickness are also important and are to be taken into account for future analysis.

It is also seen that the stresses are dependent on the non linear temperature gradients and determination of correct gradient is most important aspect of the thermal analysis of the bridge superstructure.

The results plotted show that locally layer wise layer results for longitudinal stresses at top and bottom of the deck are either both negative or both positive. The positive gradients results in compression at bottom face of the soffit while the negative gradients result in the tensile stresses at the bottom face of the soffit. In one case the temperature stresses adds to the tension at bottom due to dead loads while in another they reduce it.

Neglecting the temperature effects in bridge analysis may lead to start of the cracking in tension zone and may cause localized stresses at some parts of the bridge deck.

A parameter study was undertaken to determine the effects of various quantities on the response of the Jaipur Bridge using temperature data from the field test. Heat conduction and/or static analyses were performed to determine the effects of the following parameters:

1) a small variation, I^{o}F, of the initial uniform temperature distribution assumed for the slab
2) The temperature distributions present in one or more of the following components of the structure: a) the sidewalks, b) the parapets, and c) the element joining the sidewalk and and slab

Different Zone Stresses

A complete three dimensional sequentially coupled (thermal structural coupling) analysis has been carried out for the reference section for six different temperature gradients ie summer, spring and winter – positive and negative gradients for each ie 3x2=6

The stress values obtained have been compared afterwards with the 2 D analysis results obtained for Jaipur region.

Further the analysis has been carried out for 7 zones of India as suggested by Dr A.K. Dwivedi ie Srinagar, New Delhi, Bhopal, Kolkata, Guwahati, Mumbai and Chennai

The composite bridge is 30m long. The experimental results and the results obtained from the ANSYS model

CONCLUSION OF THE RESEARCH WORK

In this work a computer program, ANSYS, which included the heat flow and thermal stress analysis in a complete system was developed. The environmental data required for input are the solar radiation intensity, ambient air temperature and wind speed. Daily solar radiation intensity is available through the Weather Bureau at selected locations while air temperature and wind speed can be obtained from local newspapers.

This program provides a all-purpose and economical method for forecasting bridge temperature distributions and the thermal stresses caused by daily environmental changes. Several types of Composite bridge cross sections can be considered. In this work, composite bridge model was prepared at Jaipur and was tested. Specific attention was given to the extreme summer and winter climatic conditions representative of the city of Jaipur.

A computational procedure for the prediction of temperature induced stresses in highway composite bridges due to daily changes in temperature is developed. The procedure has been implemented with the help of ANSYS, computer program which is able to predict both the temperature distribution and the temperature induced stresses for a variety of bridge types. This work is of particular significance because the important environmental data required in the analysis such as solar radiation, ambient air temperature and wind speed are available from daily weather reports. A two-dimensional finite model is used for forecasting the temperature distribution while ordinary beam theory is used for predicting the bridge movements and stresses due to temperature changes. Outgoing long-wave radiation, which has not been considered in the past, was included in the finite element temperature model, thus allowing for a continuous temperature prediction over a given period of days and nights.

Recommendation of further Study of the work

During the course of any investigation, several questions arise as an outgrowth of the research. Most of these questions are beyond the scope of the study and remain unanswered. From a practical standpoint, the following studies of immediate value for the development of a simplified design procedure to account for the thermal behavior of bridge structures need to be conducted:

1) Thermal behavior study of the concrete deck in the vertical and transverse directions.
2) Effect of diaphragms study and supports on transverse action.
3) Effect of non composite areas on deck stringer thermal interface forces and stress variations.
4) The effect of slab reinforcing on the transfer of heat through a concrete bridge deck, i.e., temperature distribution should be studied.

Another topic of practical interest is the use of the computer program ANSYS, developed in this work to serve as a design tool to determine the larger temperature induced stresses in the bridge under investigation. After stresses have been defined, they can then be superimposed with the dead load and live load stresses in order to obtain the final design stresses.

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