Fire resistanceof steel-concrete composite bridge girders

Venugopal, A., George, T.

Abstract: Bridge fires have become relevant issue in recent years due to rapid development of navigational systems as well as increasing transport of hazardous materials. Fire is one of the most dreadful hazards that bridges may be subjected to during their whole lifespan. Due to high intensity of fires, significant structural damage, even collapse of bridges occur which lead to large economic loss and traffic delay. In this paper, the fire response of a composite bridge girder is evaluated using the FEM computer program ANSYS. Numerical simulation results demonstrate that the composite action from steel-girder–concrete-slab interaction significantly elevates the fire resistance of a composite bridge girder under fire conditions.

Index Terms: Bridge fires, Fire resistance, Shear connectors, , Thermo-structural analysis

I. INTRODUCTION

Bridge fires caused by crashing of vehicles with different components of bridges and burning of highly flammable gases are much more hazardous than building fires and are differentiated by a rapid heating rate and a higher peak temperature which could lead to bridge collapse. Bridge failures during a fire can result in the disruption of commerce and services, and most importantly the loss of human life. The fire thus produced is highly dangerous as compared to building fires and they spread in different directions with rapid heating pace. These high intensity fires can pose a severe peril to structural members and can lead to disintegration of structural members of a bridge.The most significant example is the demolition of the I-20/I-59/I-65 interchange in Birmingham, AL, USA on January 5, 2002.A gasoline tanker overturned and started a fire under the bridge. The main span sagged about 3 meters and the bridge had to be replaced. The bridge damage level was estimated to be 4 [3]. Construction of composite steel-concrete composite bridges is a major trend in recent years. Advantageous properties of both concrete and structural steel are effectively utilized in a composite bridge. Due to the composite action developed, all loads including traffic, surfacing, wind, water, pressure, seismic loads) are shared by the steel/concrete composite. They are endowed with higher strength, ductility, and less dead weight. Nevertheless, steel structural members exhibit lower fire resistance when compared to concrete members due to rapid rise in steel temperatures resulting from different thermal properties such as high thermal conductivity, low specific heat, and lower sectional mass of steel. This ultimately leads to reduced load carrying capacity under fire conditions.

Fig. 1. Bridge constructed over ZolotoiRog Bay caught fire

The steel structure of a bridge is connected to the concrete structure of the deck so that the steel and concrete act together, and thereby reducing deflections and enhancing stiffness. This is accomplished by ‘shear connectors' connected to the steel beams and then embedded in the concrete. Steel–concrete composite beams are mainly used in bridges and industrial buildings due to their potential in developing high flexural strength and stiffness. Structural steel sections with no fire insulation, when subjected to fire, are having limited fire resistance due to the rapid rise of temperature in the member. This rapid rise in temperature is pursued by a rapid loss in strength and stiffness. Fire resistance can be significantly increased when steel elements interact with structural materials characterized by low thermal conductivity such as concrete. Even though bridge fires pose a real threat, this field is not considered in current design codes. In current practice, there are no special measures adopted for enhancing structural fire safety of bridge girders. Moreover, there is very limited information and research data in the literature on the fire resistance of structural members in bridges. This paper presents results from an analytical study on the fire rating of composite bridge girders.

II. OBJECTIVES

The main objective of this project work is:

- To study the fire resistance of symmetric steel-concrete composite bridge girder of symmetric when subjected to fire
- To investigates the influence of composite action and stiffeners on the response of girder under fire.

III. MODELLING

A numerical study is carried out using the FEM computersoftware ANSYSto illustrate the response of a steel girder exposed to fire.

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For thermal and structural analyses, two sets of discretization models has been developed. The thermal-analysis results are imported to structural model and applied as thermal-body load on it uniformly along the girder span. Thermal and mechanical properties of steel and concrete have been incorporated in the analysis. ASTM E119 fire curve is given as fire load. Deflection limit state is adopted for defining failure, and the failure is said to occur when the deflection becomes span/20.Both heat-convection and radiation loads have been applied at the exposed surface areas of the solid element. Convection coefficient of $\alpha = 35W/m^2 {}^\circ C$ is used in the thermal analysis under and this is based on Eurocode 1[European Committee for Standardization (CEN) 2002] recommendations. A Stefan-Boltzmann radiation constant of $5.67x10^{-8}$ $W/m^2 {}^\circ C$ is applied in the thermal analysis.

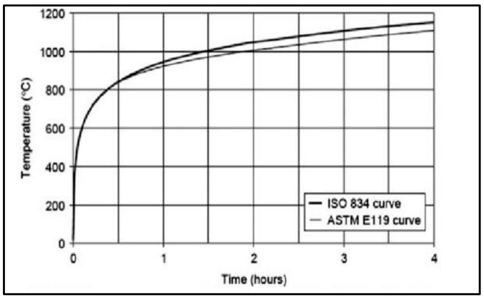

Fig. 2. Fire loading curve

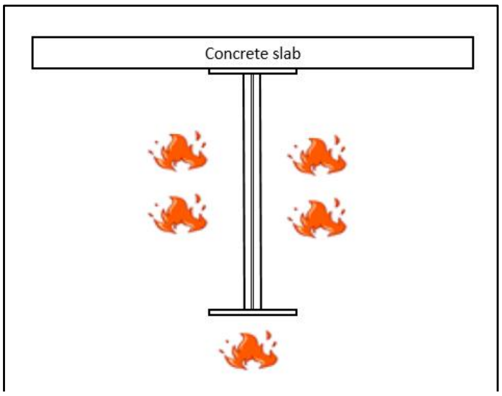

Fig. 3. Fire exposure

A. Discretization for Thermo-structural analysis

The thermal analysis of the steel-concrete girder is carried out using, SOLID70 elements and SURF 152 elements. SOLID70 has a three-dimensional thermal conduction capability. The element has eight nodes with a single degree of freedom, temperature, at each node. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element also can compensate for mass transport heat flow from a constant velocity field. LINK 33 is used to model the reinforcement. To account for the action between the concrete slab and the top flange of the steel girder, bonded contact is considered. SURF152 is used for thermal load and surface effect applications. The whole model has been meshed with 50mm size after conducting mesh convergence study. For welding simulation bonded contact modelling has been used. Linear analysis is considered in contact modelling (bonded contact).

For structural analysis, the bridge girder was modelled with two elements, namely, element SHELL181 and SOLID185. For the bottom flange, web, top flange, and stiffeners, SHELL 181 is used and for concrete slab SOLID 185 is used. SHELL181 can capture buckling of flange and web as well as lateral torsional buckling of the member and therefore is well suited for large-rotation, large-strain, and nonlinear problems. SOLID185 has eight nodes with three degrees of freedom, namely, three translations in the x, y, and z-directions. This element is used for 3D modelling of solids with or without reinforcement and is capable of accounting for cracking of concrete in tension, crushing of concrete in compression, creep, and large strains. To the structural model, the output from thermal analysis has been imported as thermal load. Node merging concept has been adopted for composite action simulation between concrete deck slab and steel beam. The model is shown in fig 3.

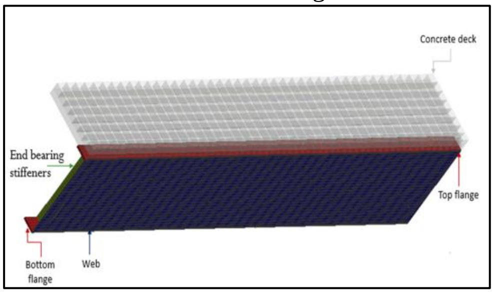

Fig. 4. Composite bridge girder modelled in ANSYS

B. Methodology

The thermal properties of component materials, namely, thermal conductivity, specific heat, and thermal expansion, which vary as a function of temperature are given as input to determine the thermal progression among steel beam and concrete slab. Reduction factor for modulus of elasticity of steel and concrete at each temperature is also considered. The mechanical properties of steel and concrete were also given as input. The thermal and mechanical properties of steel and concrete are adopted from Eurocode 2 (CEN 2004) and Eurocode 3(CEN 2005) codes.

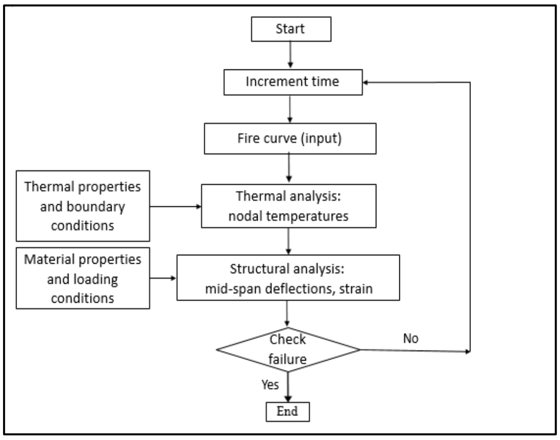

Fig. 5. Thermo-structural analysis

The methodology for this work is explained as a flowchart in fig.5.

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C. Model Validaton

The validation process comprises of comparison of thermal results from the analysis with that obtained from the fire test conducted by Aziz [1]. The fire analysis experiment is conducted inside a specially designed furnace. The analysis is carried out with the mesh discretization of 50mm size and material properties. The assembly is exposed to ASTM E119 fire exposure as in the fire test. The geometric and materiel properties of the tested girder are taken from the literature.

Fig.6 shows a comparison of predicted temperatures by the FEM model with those measured in the fire test. It can be seen that percentage error is about 3-4% when comparing the FEA and experimental results. This slight difference can be imputed to the change in the heat-transfer parameters, such as emissivity and convection coefficients used in the analysis compared with the actual values in the test (furnace).

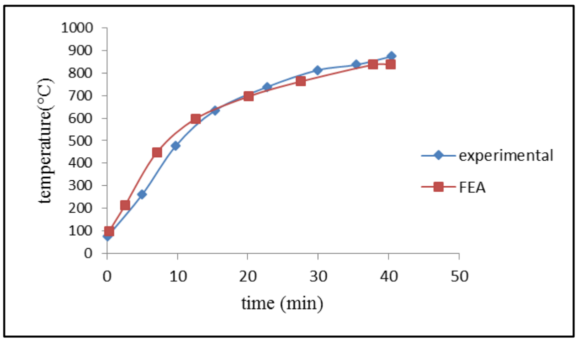

Fig. 6. Comparison of temperatures in bottom flange as per FEA analysis with test data

D. Case study

To evaluate the response of a typical bridge girder under fire conditions, a simply supported steel bridge girder is selected for analysis. The bridge consists of five girders supporting a RC slab 200mmthick. The steel girder is assumed to be in full composite action with the slab. The bridge girder is 25.8 m span length. The girders are fabricated from 415 MPa steel and the concrete used in the slab has a compressive strength of 25MPa.

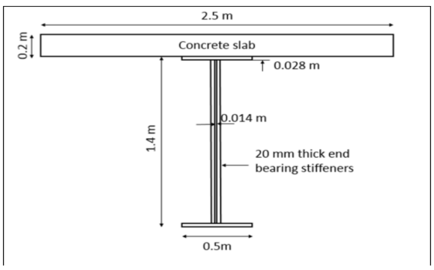

Fig. 7. Cross section of the girder

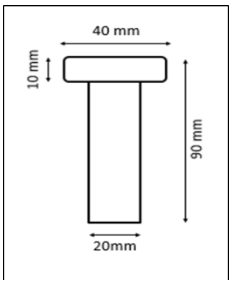

Fig. 8. Cross section of shear stud

IV. Results and Discussions

The thermo-structural analysis on the girderis carried out under the loading which consists of dead load plus live load and thermal load.The dead loads include self-weight of the girder, self-weight of effective width of concrete slab, and weight of wearing coat which is 14.5kN/m. For the live load, a uniformly distributed load of 9.5kN/m representing Class AA wheeled vehicle is considered. Symmetriccriteria is considered for analysis.

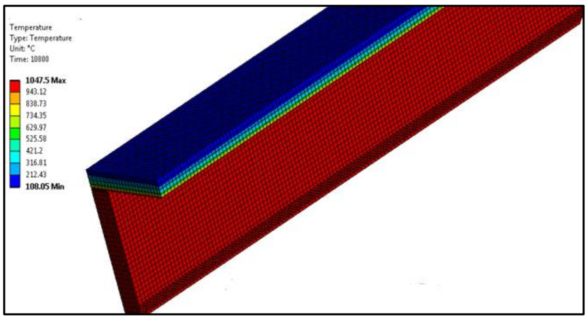

Fig. 9. Thermal distribution along cross section

Fig.9 shows the temperature distribution of the steel-concrete composite bridge girder with time. The maximum temperature applied is 1047.6ºC. It can be seen that maximum temperature occurs within steel due to high thermal conductivity of steel.

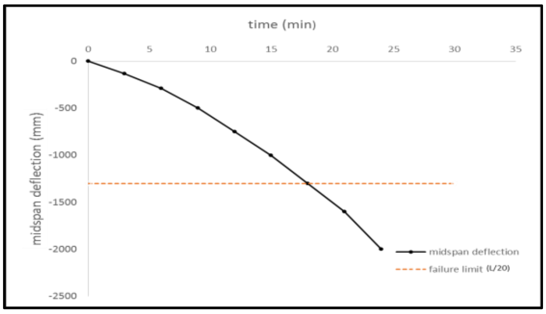

Fig. 10. Effect of midspan deflection on thermo-structural loading

From fig.10 it is observed that the fire resistance of the bridge girder is about 18 minutes. It is also observed that mid-span vertical deflection increases linearly with fire exposure time initially. With the increase of temperature, higher rate of midspan deflection is observed, which is due to the strength reduction resulting from increased temperatures in the steel girder. The third stage includes rapid increase in deflection which ultimately results in spalling of concrete and finally collapsing of the structure. This is because of the formation of plastic hinges in the steel beam and also buckling of the web.

A. Influence of composite action

In order to study the effect of composite action on response of girders under fire conditions, girder with partial shear connection as well as girder with no composite action is considered.

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From Fig.11 it can be seen that maximum fire resistance is for girders with full composite action since it transfers load from fire induced steel beam to deck slab and thereby reducing deflection.

Table 1. Influence of composite action

Parameter	Fire resistance(min)
No composite action	17.1
Partial composite action	18

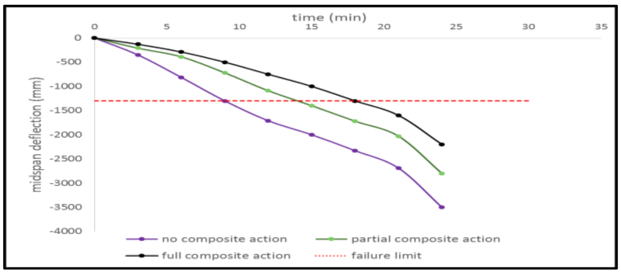

Fig. 11. Effect of composite action on thermo-structural loading

B. Influence of stiffeners

To investigate the effect of stiffeners on fire resistance, the girder is analyzed considering two cases. First case includes girder with midspan and end bearing stiffeners. Second case includes girder with end bearing stiffeners only. The results shown in Fig.12 indicate that no fire resistance enhancement is indicated with including the stiffeners.

Table 2. Effect of stiffeners

Parameter	Fire resistance(min)
Unstiffened girder	17.6
Stiffened girder	18

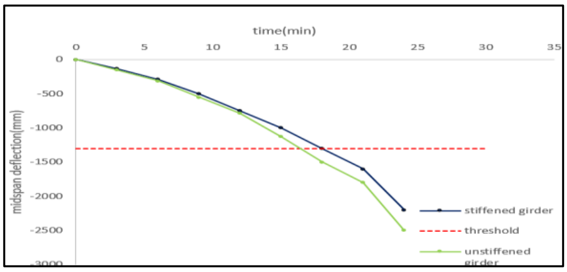

Fig. 12. Influence of stiffeners on thermo-structural loading

C. Influence of web thickness

Varying the thickness of web changes the slenderness ratio and this variation is plotted in Fig.13

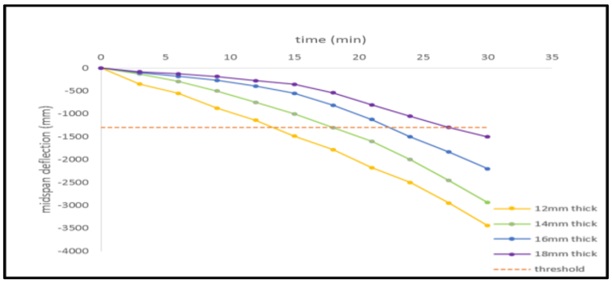

Fig. 13. Effect of web thickness on the response of steel bridge girders

Table 3. Effect of web thickness

Web thickness (mm)	Slenderness ratio	Fire resistance(min)
12	112	13.5
14	96	18
16	84	22.5
18	75	27.3

V. CONCLUSION

The following are the conclusions obtained from this study:

- The fire resistance of the girder with composite action is twice the girder with no composite action. Hence composite action plays an important role in enhancing fire resistance.
- Presence of stiffeners does not have significant effect in increasing fire resistance
- An increase of 21-33% in fire resistance is observed by increasing the web thickness of the steel beam

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