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Finite Element Analysis of Concrete Trapezoidal Box Girder under Thermal Loading

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Abstract
Although bridges are designed to last for a hundred years, they are usually used for much longer periods of time. Thermal effects occur on a daily, seasonal, or annual basis, depending on the environmental conditions. However, there are limited studies and test data on the thermal impact of concrete box girders, focusing on models developed through numerical analysis and field measurements. Temperature distributions on concrete bridges are nonlinear, causing stress distributions to self-equilibrate; to discuss the stresses, deflections, and moments caused by temperature variations, the three-dimensional finite element ANSYA program is used to analyze concrete box girder bridge specimens with trapezoidal cross sections. In this paper, three cases of concrete box girders are studied. A parametric analysis is carried out to investigate the effect of thermal loading on the behavior of concrete girders. Three instances of thermal load are studied: the thermal load applied at the upper, bottom, and upper bottom flange of the girder. The numerical results are compared with experimental results, and thermal loading is applied to three box girders in different regions. The numerical results showed that the minimum stress in the longitudinal direction (Z) is 1.28 MPa when the thermal load is applied to both the upper and bottom flanges of the box girder.

Keywords: Finite Element, Concrete, RC, Box-Girder, Thermal Loading, Analysis

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1. Introduction

A box girder is used as a superstructure composed of two or more vertical or inclined webs joined by top and bottom flanges to form a single or multi-cell box girder. This construction's cross section is either trapezoidal or rectangular [1]. The cellular structure of the box girder is the result of removing unnecessary materials, which decreases dead weight and, hence, lowers cost. The box girder offers several benefits over the other sections, including stronger and torsional stiffness and strength than the open section, a larger span range than the T-beam (resulting in fewer piers, and a more cost-effective design because of its hollow section [1].

The increase and decrease of temperatures are some of the most critical factors influencing bridges. Temperature fluctuation is determined by the structure's orientation, material, deck surface finishing layer, structural size, and cross-section geometry. Bridges' performance may be altered by the nonlinear heat load generated by this phenomenon [2]. Zhao et al. [3] modeled box girders by the finite element method and the experimental findings were compared to the finite element analytical results derived by MIDAS/Civil [3] and [4] introduce this study the creep and shrinkage of a box girder using an implanted vibration wire strain gauge [5]. recently investigated the behavior of box girder bridges using the FEM and discovered it appropriate

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and beneficial in studying the box sections based on Vlasov's thin-walled beam structural theory. They constructed the balancing differential equation of a double-symmetric box girder.

A temperature analysis technique was developed as a result of static loading testing on pre-stressed concrete. concrete box girder bridges by Khadiranaikar and Tiger [6]. The spatial FE technique was utilized to study the dynamic response of a thin-walled box girder [7].

A pre-stressed concrete bridge fire broke out on Arizona's Bill Williams River Bridge in 2006. It was built with 14 spans totaling 23.2 meters in length, supported by a pre-stressed concrete girder superstructure beneath a cast-in-site concrete slab. In 2017, another devastating fire broke out on the I-85 highway in Iowa, forcing a PC bridge to fail after 40 minutes [8].

In this study, a 3-dimensional finite element ANSYS program is used to model the concrete box girder bridge specimens with trapezoidal cross sections. In this paper, three cases of concrete box girders are studied. A parametric analysis is carried out to study the impact of thermal loading on the behavior of concrete girders.

2. Finite Element Modeling

Solid 65, a solid element with eight nodes, was used to simulate the concrete. The Solid65 consists of 8 nodes, each with 3 D.O.F for translation in the x, y, and z directions. The material may flex plastically, shatter in 3 orthogonal directions, and crush. Fig. 1 shows the element geometry.

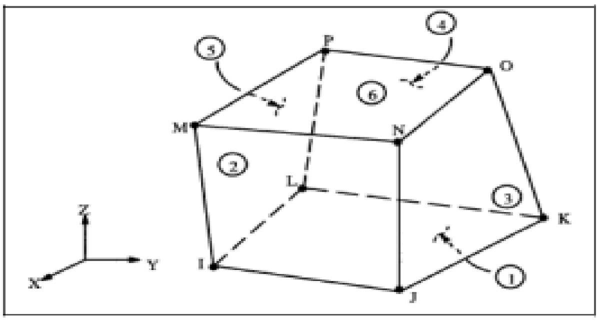


Fig. 1 Solid 65 Element (ANSYS Help) [9].

The steel reinforcement was modeled using a Beam 188 element. This element requires two nodes to function properly. Each node has 3D.O.F, which corresponds to translations in the x, y, and z dimensions. Plastic deformation of the element is also possible. Fig. 2 depicts this element type's shape and node placements.

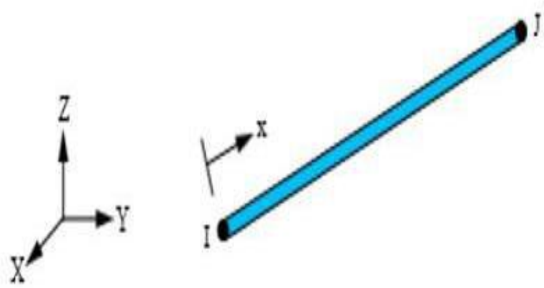
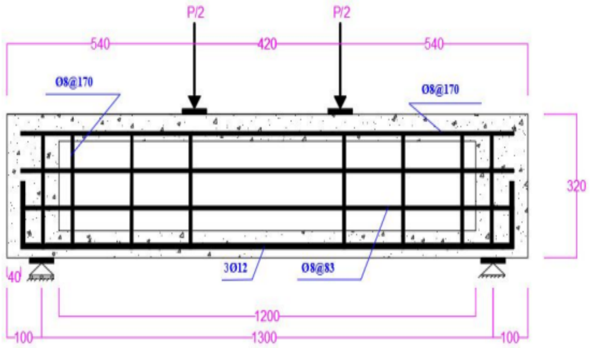


Fig. 2 Beam188 Element (ANSYS Help) [9].

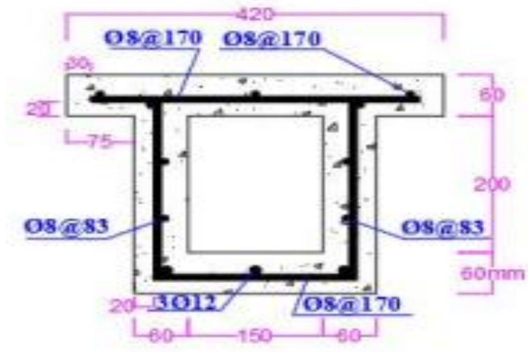
3. Verification of Finite Element model

The experimental investigation has been considered to verify the model in ANSYS. The box girder is used to examine the thermal loading bridge structural reaction by Zuhdiy, et al. [1] the authors chosen box girder was composed of one lower slab, two webs, and one upper slab as shown in show Fig. 3, with simple supported ends, the specimen dimensional of 1500 mm actual length, 320 mm overall height, 420mm top flange width, 270mm bottom flange width, and 6 cm flange height and web width. The reinforcement at the bottom of flange 3Ø 12 mm and the reinforcement at the top of flange 5Ø8 mm @170mm, the web reinforcement Ø8@83mm, Fig. 3 shows the dimensions and reinforcing information. In this paper, box girders were modeled and analyzed using ANSYS.

ISSN: 2073-9524
Pages:15-21



a) Simple Supported RC Box Girder.



b) Cross-section of RC girder.

Fig. 3 Dimensions and reinforcing details (all in millimeters) [1].

By considering the symmetry of the box girder, half of the girder modeling contains loading and supporting. Fig. 4 shows the finite element modeling. Table 1 shows the Details of the Elements used in the analysis.

Mesh density selection is a crucial stage in finite element modeling; when an appropriate number of elements are utilized in a model, the results tend to converge. This is practical when an excess in mesh density has little influence on the outcomes. As a result, in this FE modeling, a convergence analysis is performed to establish the suitable mesh density.

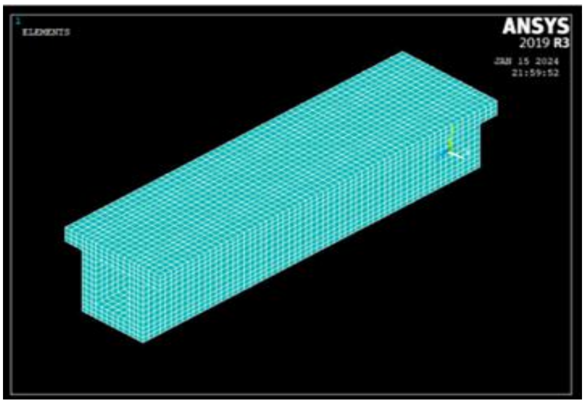


Fig. 4 Finite element meshing of RC box girder

Table 1: Details of Elements

	Material model	Element type
Concrete	Multilinear and isotropic	Solid65
Steel	Bilinear and isotropic	Beam188
Plate	Bilinear and isotropic	Shell181

The ultimate deflections (vertical displacements) of the box girder's bottom face and bottom flange were measured in the middle of its span. Table 2 illustrates the comparison of numerical and experimental findings for the ultimate load and maximum deflection.

Table 2: Experimental and numerical results for ultimate load and maximum deflection.

	Ultimate load (kN)	Maximum deflection (mm)
Experimental	308	8.9
Finite Element	285	6.4

Fig. 5 shows the comparison of experimental and numerical data for the box girder's load and deflection. There is a good agreement between the analytical and experimental results.

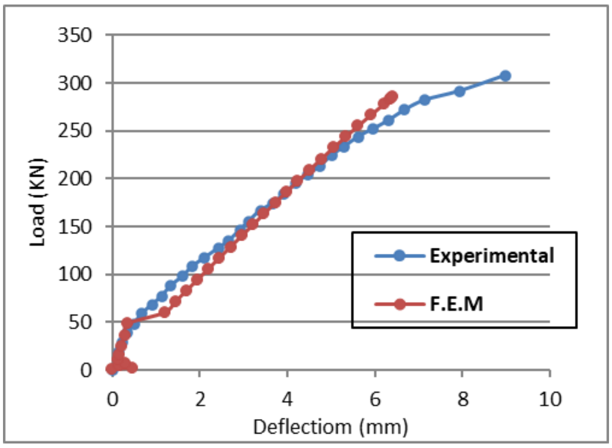
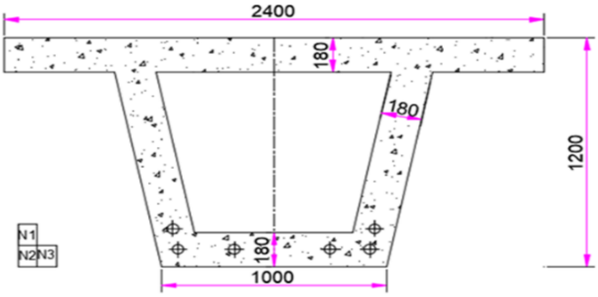


Fig. 5 Load Deflection curves for Experimental and Numerical results.

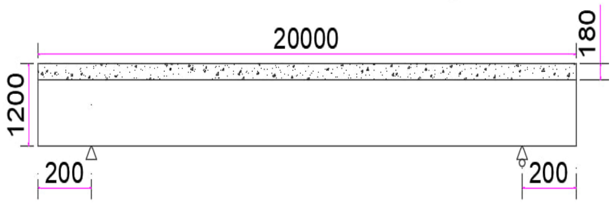
 ISSN: 2073-9524
Pages:15-21

4. Effect of Thermal Loading on Concrete Box Girder

In this paper, the influence of thermal loading on concrete box girders was studied. A thermal load of 50°C was applied only with temperature reference 25°C, without any structural load. The box girder, shown in Fig. 6, has a 20000 mm span length and a sectional height of 1200 mm. It is made of one lower slab, two webs, and one upper slab with simply supported ends. The top slab is 2400 mm in width and 180 mm thick, while the bottom slab is 1000 mm in width and 180 mm. The web is also thick, 180 mm. Additionally, both ends were supported with steel plates, each 10 mm thick. the material of the box girder is concrete with a 30 MPa compressive strength.



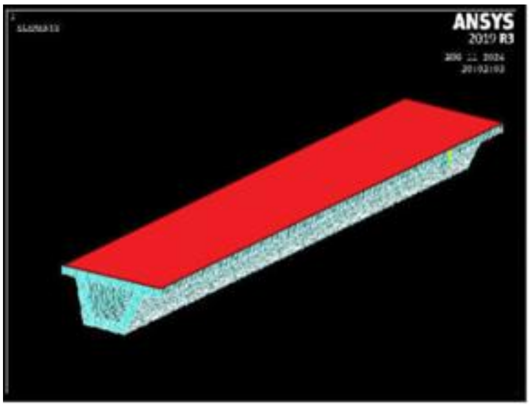
a) Cross section



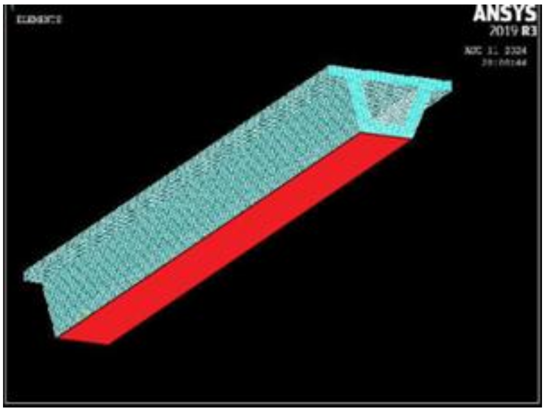
B) Loading and Boundary Condition

Fig. 6 The Proposed Concrete Box Girder (all dimensions are in mm).

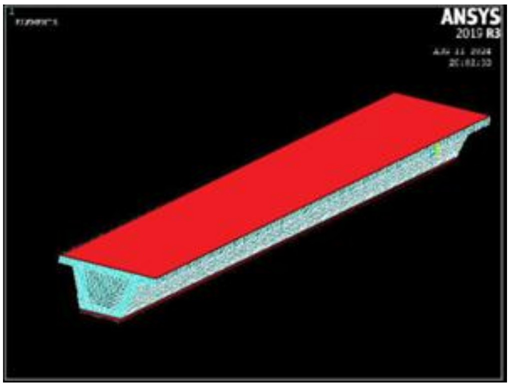
To examine the effect of thermal loading on concrete box girders, the proposed simply supported concrete box girder was chosen and the analysis was carried out by the ANSYS program. This study considered a nonlinear FE analysis for the concrete box girders. Fig. 7 shows the thermal load considered for the parametric study.



a) Girder1(Thermal load at Upper Flange)



b) Girder2 (Thermal load at Bottom Flange)



c) Girder 3 (Thermal load at Upper and Bottom flange)

Fig.7: The proposed Girders.

https://doi.org/10.56990/bajest/2025.040102
Pages:15-21

4. Result and Discussion

Table 3 shows the maximum deflection and the maximum longitudinal stresses in the direction (Z) in a concrete box girder exposed to thermal loading at a temperature of 50°C.

Table 3: Result of the effect of thermal loading on concrete box girders.

	Location of thermal loading	**Deflection (mm)**	**Stress in Z direction** (Mpa)
Girder1	Top Flange	2.57	1.35
Girder2	Bottom Flange	2.67	1.40
Girder3	Top and Bottom flange	2.60	1.28

Figs. 8-10 show the deflected shapes for the three girders. From Fig. 10, it can be seen that the maximum deflection is 2.67 mm when the heat load is applied to the bottom flange of the concrete box girder. From Figs. 8-10, it is seen that when the top surface of the bridge is hotter than the bottom, the deflection is upward, and vice versa, when the top surface is less hot than the bottom, the deflection is downward.

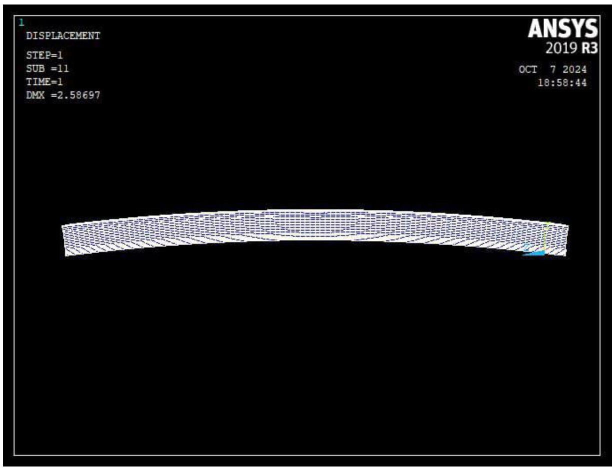


Fig. 8 The deflected shape for Girder1

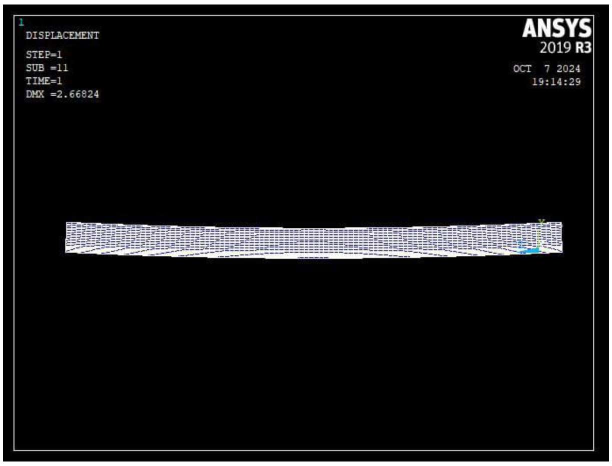


Fig. 9 The deflected shape for Girder2.

Fig. 10 The deflected shape for Girder3.

The Figs (11-13) show the stresses of Von Mises for the three girders. From Fig.13, it is noted that the minimum stress in the longitudinal direction (Z) is 1.28 MPa when the thermal load is applied to both the upper and bottom flanges of the concrete box girder.

In Girder 1, the numerical results showed the effect of the thermal load on the concrete box girders, indicating that the smallest deflection, 2.57 mm, occurred in the upper slab of the concrete box girder. The numerical results of the nonlinear analysis also indicated a stress reduction, with the minimum stress in the longitudinal direction (Z) being in Girder3, 1.28 MPa.

https://doi.org/10.56990/bajest/2025.040102
Pages:15-21

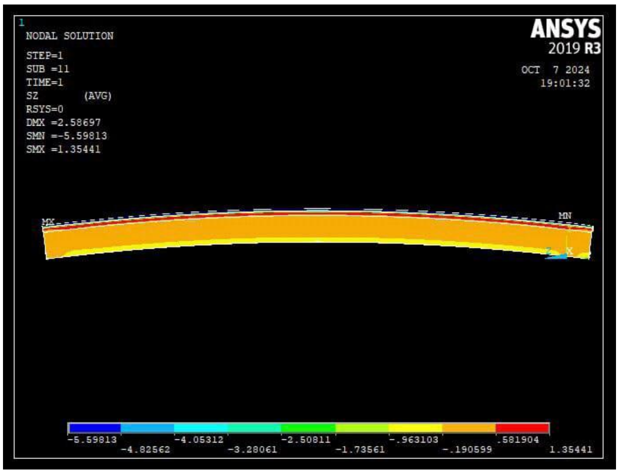


Fig. 11 The Von Mises Stress for Girder1

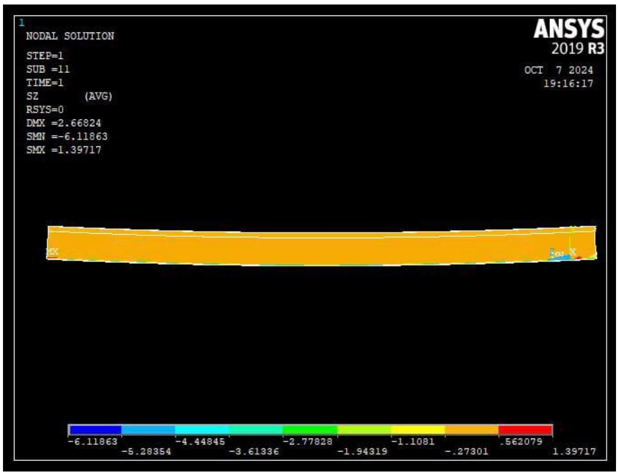


Fig. 12 The Von Mises Stress for Girder2.

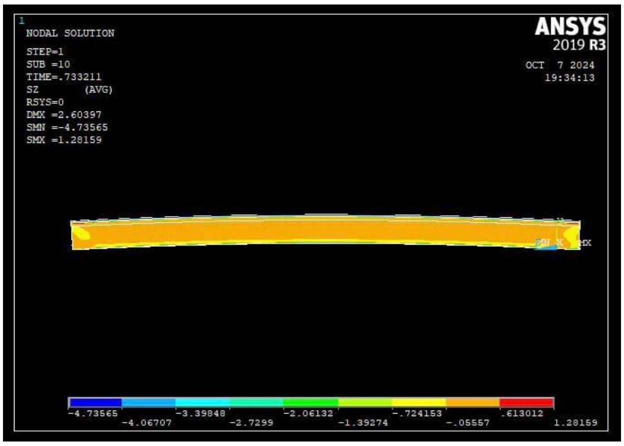


Fig. 13 The Von Mises Stress for Girder 3.

5. Conclusion

The thermal influence of concrete box girder bridges is a major issue while designing the bridge. The current paper studies the thermal loads affecting concrete box girder bridges with a trapezoidal cross-section at 50°C.

The behavior of box girders was studied using a 3D nonlinear FEM. To validate the numerical analyses, experimental box girders from the literature were selected, and the test results and numerical model showed good agreement. Using the developed finite element model, a parametric study was presented to examine the influence of thermal loading on box girders. From the analytical findings, the following conclusions were drawn.

1. In Girder 1, the numerical results showed the effect of thermal load on the concrete box girders, indicating that the smallest deflection, 2.57 mm, occurred in the upper slab of the concrete box girder. The numerical results of the nonlinear analysis also indicated a reduction in stress, with the minimum stress in the longitudinal direction (Z) being in Girder3, 1.28 MPa.
2. When the top surface of the bridge is hotter than the bottom, the deflection is upward, and vice versa, when the top surface is less hot than the bottom, the deflection is downward.
3. In Girder 1, the numerical results showed the effect of thermal load on the concrete box girders, indicating that the smallest deflection, 2.57 mm, occurred in the upper flange of the concrete box girder.
4. In Girder3, it is shown that the minimum stress in the longitudinal direction (Z) is 1.28 MPa when the thermal load is applied to both the upper and bottom flanges of the box girder.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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