Thermal Stress Analysis of Concrete Box Girder Segment Using Abaqus

Jayesh Anil Patil[1], Prof. Girish Joshi[2]

[1]Jayesh Anil Patil, Department of Structural Engineering G H Raisoni College of Engineering and Management Wagholi, Pune, Maharashtra, India

[2]Prof. Girish Joshi, Department of Structural Engineering G H Raisoni College of Engineering and Management Wagholi, Pune, Maharashtra, India

Abstract* - *This study investigates the thermal behavior of a double-cell concrete box girder bridge segment under temperature gradients as specified in IRC:SP:6 using ABAQUS finite element analysis. A three-dimensional finite element model was developed with appropriate material properties, boundary conditions, and thermal loading to simulate real bridge conditions. The temperature gradient applied across the girder depth caused non-uniform thermal expansion, leading to thermal stresses and structural deformation. The analysis evaluated temperature distribution, Von Mises stress, principal stress, strain, and displacement within the girder segment. Results showed that the top slab experienced the highest temperature due to thermal exposure, while the bottom slab remained comparatively cooler. This differential heating created thermal curvature and significant stress concentrations at the web-slab junctions and bottom flange regions. The maximum thermal stress observed was within the allowable range for concrete, while displacement remained within serviceable limits. Manual calculations were also performed to validate the numerical simulation results. The comparison confirmed the reliability of the finite element analysis approach. The study highlights the importance of considering thermal loads in bridge design to prevent cracking and serviceability issues. Thermal effects significantly influence the durability and long-term structural performance of box girder bridges. The findings provide useful insights for improving thermal stress consideration in practical bridge engineering design.

Keywords: ABAQUS (fem analysis), concrete box girder, thermal stress, IRC:SP6, temperature gradient.

I. INTRODUCTION

Bridges are vital for transportation, linking urban centers, rivers, and valleys. The capacity of a bridge dictates the volume and weight of traffic it can handle, though higher capacity often increases costs. Striking a balance between projected traffic demands and the expense of a larger bridge structure is essential. To address economic, visual, and ecological needs, bridges may incorporate extended spans, fewer girder lines, and minimal substructure components. Effective teamwork among engineers, manufacturers, and builders enables the seamless construction of standardized precast, pretensioned girders, which have been refined by various states.

The need for long-span bridges has grown due to urban traffic congestion and waterway navigation demands. Extended spans are critical for modern infrastructure, supporting safety, environmental considerations, and cost-effectiveness. Over time, bridge construction methods have evolved significantly. Techniques for planning, designing, and building bridges are continually improved to ensure feasibility, construction simplicity, safety, maintainability, and affordability. Precast, pre-stressed concrete girders, widely adopted across states for over six decades, are favored for their durability, cost-efficient life cycle, and modular design.

II. LITERATURE REVIEW

Shen et al. [1] investigated the temperature distribution across the thickness of concrete box girders using field monitoring and finite element analysis. The study revealed highly nonlinear temperature gradients, particularly in the top slab, where temperature differences reached significant values, leading to tensile stresses in inner layers. Although the research provided detailed insights into thermal variation, it was limited to specific case conditions and lacked generalization for varying climates.

Thakkar et al. [2] presented a comprehensive review on fragility analysis of bridge structures, emphasizing the role of environmental factors such as temperature in influencing structural vulnerability. The study highlighted the importance of probabilistic approaches for assessing bridge safety; however, it did not focus specifically on thermal stress distribution in box girder bridges.

Do et al. [3] analyzed early-age temperature development and cracking risk in segmental box girder diaphragms using a three-dimensional finite element model. The results indicated that significant thermal gradients between the core and surface increase tensile stress and cracking potential. Despite its accuracy, the study was confined to construction-stage behavior and did not address service-stage thermal effects.

Liu et al. [4] examined temperature variations in concrete bridge girders through finite element simulation and experimental validation. The findings showed that actual temperature gradients are nonlinear and may differ from standard code assumptions. However, the study did not provide a universally applicable model for different environmental conditions.

Xiao et al. [5] studied hydration heat effects in concrete box girders using numerical simulation. The results demonstrated that internal temperature rise during casting leads to self-induced stresses and potential cracking. While the study incorporated time-dependent material properties, it focused only on early-age behavior and excluded environmental thermal loading during service.

Abid et al. [6] conducted a thermo-mechanical analysis of concrete box girders under environmental conditions using a validated three-dimensional finite element model. The study showed that thermal stresses can reach significant magnitudes and produce noticeable displacements. However, the use of generalized temperature inputs limits its applicability to region-specific conditions.

Tayşi and Abid [7] performed experimental and numerical investigations on temperature distribution in box girder bridges. Their findings indicated that thermal properties of concrete significantly influence temperature gradients, which may exceed code-specified limits. The study, however, emphasized temperature variation rather than detailed structural stress evaluation.

Liu et al. [8] developed an empirical prediction model for temperature gradients in bridge members based on field measurements and meteorological data. The study highlighted the influence of solar radiation, wind speed, and structural orientation on temperature variation. Despite improving prediction accuracy, the model was limited to specific structural forms and did not incorporate full structural analysis.

Do et al. [9] investigated temperature evolution and cracking risk in high-strength concrete due to hydration heat. The study showed that increased cement content leads to higher thermal gradients and increased cracking potential. However, the research primarily focused on construction-stage effects and did not consider long-term environmental thermal behavior.

Do [10] proposed a combined finite difference and finite element approach for predicting temperature and stress development in early-age concrete members. The model improved prediction accuracy of thermal behavior but was applied mainly to simplified structural elements, limiting its applicability to complex bridge geometries.

Yang et al. [11] studied the time-lag effect between temperature variation and structural response in concrete box girder bridges using field monitoring data. The results revealed that thermal strain does not occur instantaneously, leading to hysteresis behavior in temperature–strain relationships. Although the proposed method improved data interpretation, it was not integrated into structural design models.

Lantsoght et al. [12] evaluated the fatigue performance of prestressed concrete bridge systems through experimental investigation. The study demonstrated that compressive membrane action enhances structural capacity under repeated loading. However, the interaction between fatigue behavior and thermal stresses was not addressed.

Maguire et al. [13] conducted long-term monitoring and load testing of a segmental box girder bridge to investigate thermal distress. The study found that thermal gradients significantly influence crack openings, often exceeding design assumptions. While providing valuable field data, it lacked predictive modeling of thermal stresses.
Wang et al. [14] analyzed thermal behavior in concrete box girder arch bridges using both two-dimensional and three-dimensional finite element models. The results showed that thermal loads can be comparable to dead loads and that two-dimensional models are insufficient for complex geometries. However, the study did not incorporate region-specific design codes.

Evsukoff et al. [15] developed a data-driven model for predicting temperature rise in concrete due to hydration using data mining techniques. The model provided accurate estimation of thermal evolution based on material properties, but it did not extend to structural stress analysis or bridge-specific applications.

Branco and Mendes [16] investigated thermal actions in concrete bridges using finite element heat transfer modeling. The study emphasized that simplified assumptions in design codes may lead to inaccurate estimation of thermal stresses. However, it did not integrate detailed structural response analysis.

Massicotte et al. [17] examined the structural behavior of a prestressed segmental box girder bridge experiencing excessive deflection and cracking. The study identified insufficient prestressing and underestimated thermal effects as major causes of distress. While practical strengthening solutions were proposed, detailed thermal stress modeling was not included.

Elbadry and Ghali [18] analyzed thermal stresses and cracking behavior in concrete bridges through analytical methods. The study showed that nonlinear temperature distributions can induce significant tensile stresses, particularly in box sections, leading to cracking. Although foundational, the study relied on simplified assumptions and lacked validation using modern numerical techniques.

REFERENCES

[1] Shen, Q., Chen, J., Yue, C., Cao, H., Chen, C., and Qian, W., 2023, “Investigation on the Through-Thickness Temperature Gradient and Thermal Stress of Concrete Box Girders,” Buildings, 13(11), pp. 2882.
[2] Thakkar, K., Rana, A., and Goyal, H., 2023, “Fragility Analysis of Bridge Structures: A Global Perspective and Critical Review of Past and Present Trends,” Advances in Bridge Engineering, 4(10), pp. 1–28.
[3] Do, T.A., Tia, M., Nguyen, T.H., Hoang, T.T., and Tran, T.D., 2022, “Assessment of Temperature Evolution and Early-Age Thermal Cracking Risk in Segmental Concrete Box Girder Diaphragms,” KSCE Journal of Civil Engineering, 26(1), pp. 166–182.
[4] Liu, H., Wu, S., Zhang, Y., and Hu, T., 2022, “Finite Element Simulation of Temperature Variations in Concrete Bridge Girders,” Finite Difference Methods in Engineering, 19(6), pp. 1551–1560.
[5] Xiao, X., Peng, Y., and Luo, G., 2021, “Study on Hydration Heat of Concrete Channel-Box Girder,” Thermal Science, 25(2A), pp. 967–975.
[6] Abid, S.R., Taysi, N., Ozakça, M., Xue, J., and Briseghella, B., 2021, “Finite Element Thermo-Mechanical Analysis of Concrete Box
[7] Tayşi, N., and Abid, S.R., 2021, “Temperature Distributions and Variations in Concrete Box-Girder Bridges: Experimental and Finite Element Parametric Studies,” Journal of Civil Engineering, 45(3), pp. 1–26.
[8] Liu, J., Liu, Y., Zhang, G., Jiang, L., and Yan, X., 2020, “Prediction Formula for Temperature Gradient of Concrete-Filled Steel Tubular Member with an Arbitrary Inclination,” Journal of Bridge Engineering, 25(10), pp. 04020102.
[9] Do, T.A., Hoang, T.T., Bui-Tien, T., Hoang, H.V., Do, T.D., and Nguyen, P.A., 2020, “Evaluation of Heat of Hydration, Temperature Evolution and Thermal Cracking Risk in High-Strength Concrete at Early Ages,” Case Studies in Thermal Engineering, 21, pp. 100658.
[10] Do, T.A., 2020, “A Combination of Finite Difference and Finite Element Methods for Temperature and Stress Predictions of Early-Age Concrete Members,” IntechOpen, pp. 1–16.
[11] Yang, K., Ding, Y., Sun, P., Zhao, H., and Geng, F., 2019, “Modeling of Temperature Time-Lag Effect for Concrete

Box-Girder Bridges," Applied Sciences, 9(16), pp. 3255.

[12] Lantsoght, E.O.L., Koekkoek, R., van der Veen, C., and Sliedrecht, H., 2019, "Fatigue Assessment of Prestressed Concrete Slab-Between-Girder Bridges," Applied Sciences, 9(11), pp. 2312.

[13] Maguire, M., Roberts-Wollmann, C., and Cousins, T., 2018, "Live-Load Testing and Long-Term Monitoring of the Varina-Enon Bridge: Investigating Thermal Distress," Journal of Bridge Engineering, 23(9), pp. 04018069.

[14] Wang, Y., Zhan, Y., and Zhao, R., 2016, "Analysis of Thermal Behavior on Concrete Box-Girder Arch Bridges under Convection and Solar Radiation," Advances in Structural Engineering, 19(7), pp. 1043–1059.

[15] Evsukoff, A.G., Fairbairn, E.M.R., Faria, E.F., Silvoso, M.M., and Toledo Filho, R.D., 2006, "Modeling Adiabatic Temperature Rise during Concrete Hydration: A Data Mining Approach," Computers and Structures, 84(31–32), pp. 2351–2362.

[16] Branco, F.A., and Mendes, P.A., 1993, "Thermal Actions for Concrete Bridge Design," Journal of Structural Engineering, 119(8), pp. 2313–2331.

[17] Massicotte, B., Picard, A., Gaumond, Y., and Ouellet, C., 1991, "Strengthening of a Long Span Prestressed Segmental Box Girder Bridge," PCI Journal, 36(5), pp. 52–65.

[18] Elbadry, M., and Ghali, A., 1986, "Thermal Stresses and Cracking of Concrete Bridges," ACI Journal, 83(6), pp. 1001–1010.