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# Finite Element Analysis of Pre-stressed Concrete Box-Girder Under Thermal Loading

**A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering/Structural Engineering**

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ABSTRACT

Box girders are very commonly structural elements used due to their high performance and ability to reduce dead load and number of supports which leads to cost reduction. Therefore, it has become a major requirement to focus on studying the structural behavior of this type of structural element. Although bridges are designed to last for 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. The rise and fall of temperature are the most important factors affecting bridges, as temperature changes are affected by the orientation of the structure, the material, the surface finish layer, the dimensions of the structure, the cross-section geometry, and the performance of bridges may be affected by the nonlinear thermal load resulting from these phenomena.

In this study, a nonlinear finite element model was developed to study the analysis of prestressed concrete box-section bridge girders under the thermal load. Numerical Analysis was performed using **ANSYS** finite element program and was performed on different concrete box girders selected from the literature. A validation study was conducted to verify the experimental results and compare them with the numerical results.

A parametric study was conducted to investigate the effect of several selected variables on the behavior of prestressed concrete box girders. These parameters contains the effect of thermal location, number of tendons, area of tendons, and initial stress.

The results showed reinforced concrete box girder that have the minimum reduction in ultimate capacity when thermal load was applied on the top surface of the box girder, with a reduction of (2.0%) compared to the reference girder. Reinforced concrete box girder have the largest reduction in ultimate capacity when thermal load is applied to the sides of the box girder, with a h reduction of (14.2%) compared to the reference girder.

While prestressed concrete box girder have the minimum deflection of (0.84 mm) when thermal load was applied on the bottom flange, Prestressed concrete box girder have the maximum deflection (6.9 mm) when thermal load applied on the top and bottom surface of the box girder. The largest Stress in Z-direction occur in prestressed concrete girder when thermal load is applied to the lower flange, where the maximum stresses in the Z direction are (11.6 MPa).

# CHAPTER ONE

# INTRODUCTION

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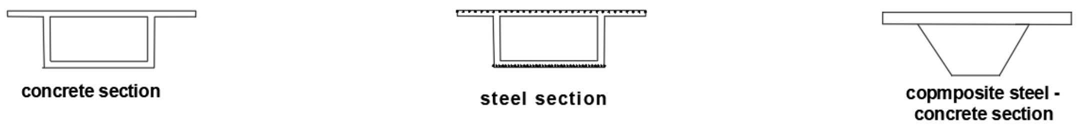
## 1 General

Bridges are superstructures that link two sides. They usually span a road or train via a natural or man-made barrier (Hemalatha et *al.*, 2021). A bridge is a structure that allows transportation to pass over an obstacle without impeding the path below. The needed crossing might be for a pipe, canal, rail, pedestrian, or automobile (Reyaz and Fathima., 2018).

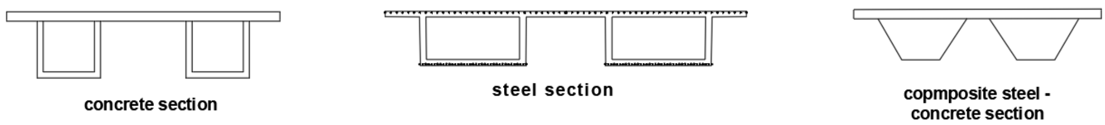
The bridge is the most responsible construction for ensuring that traffic flows smoothly (Thakai et *al*., 2016). The traditional bridge has been replaced with an innovative and cost-effective structural design as technology has evolved rapidly. The concrete box girder is one of these approaches (Miller et *al.*, 1999) and (Hanna et *al*., 2011). Bridges with short, medium, or long spans, adjacent precast, prestressed concrete box girders are an excellent choice since they are quick and simple to build (Sennah and Kennedy, 2002) (Chaitanya, 2019). A box girder may hold more weight than an I-beam of the same height. Within box girder bridges, service infrastructure such as water mains and gas pipes can be inserted. Because of its direct accessibility without the requirement for scaffolding, the massive box girder is simple to keep within.

## 1.1 Reinforced Concrete Box Girders

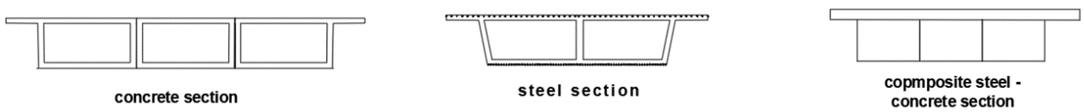
Hollow sections are commonly used in construction, including buildings, bridges, towers, and offshore structures (Hemzah et *al.*, 2020). The box is often trapezoidal or rectangular. It is made up of two web plates that are linked at the upper and lower by matching flanges. Box girders are classified into several classes based on their design, intended use, and shape. In real life, three different types of box girders are often utilized. It may be built and produced using single, double, or numerous cells. The concrete box girders are prefabricated or cast in situ(Wang and Huang, 1994) as shown in Figure (1-1).




**a):** Type of single cell Box Bridge




**b):** Type of multi spin cell Box




**c):** Type of multi spin cell Box Bridge

(Sennah, and Kennedy, 2002).

**Figure (1-1):** Box Girder of Bridges (Sennah, and Kennedy, 2002).

The section's design reduces the need for prestressing force to withstand bending moments, resulting in good structural efficiency (Benaim, 2007). A closed cell, also known as a box section, has higher torsional strength and stiffness than to an open section as shown in Figure (1-2). This is beneficial when the bridge deck is curved in plane since it can withstand high torsional stresses induced by eccentric loads. The closed section of the box girder's strong torsional strength and stiffness make it suitable to absorb torsional moments caused by curved alignments or eccentric live loads (Rodriguez, 2004).

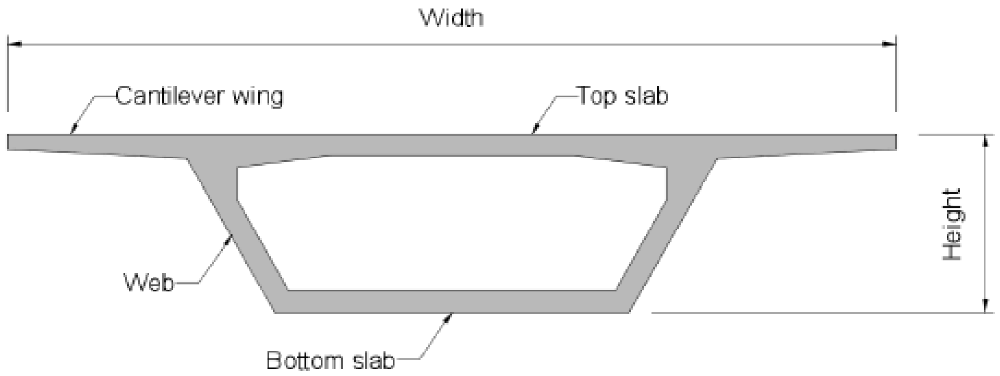



**Figure (1-2)** Cross section of single-cell Box girder (Federal Highway 2018).

The design of the box girder is strong against torsional loads and positive and negative bending moments because of its two flanges at the top and bottom (García-Segura *et al.,* 2015). Box girders have better load distribution under eccentric loads (Lin and Yoda, 2017).

## 1.2 Prestressed Reinforced Concrete Box Girder

Box concrete sections are commonly used as beams in long-span bridges to reduce dead loads and save on materials and construction costs (Hemzah, *et al.,* 2020). Box girders can have a variety of shapes and geometries. It might be rectangular, trapezoidal, circular, and composed of single or several cells. The PSC box girder bridge's stability relies on two fundamental features: form and prestressed tendons (Shah and Murudi, 2018). Multi-cell girder cross-sections may be utilized to construct bridges of practically any width by adjusting the distance between and/or the number of webs. Single-cell box girders are usually (7 to 18) meters wide, although they can be as large as (25) meters.

This wide ambit of widths for single-cell box girders is accomplished using transverse post-tensioning, which reduces tensile stresses induced by permanent dead and live wheel loads.

Prestressed concrete, structural steel, or reinforce concrete are commonly utilized in box girder construction, which can be segmented precast or cast in place, Figure (1-3) shown, "cast in site box girder" (Chaitanya, 2019).

**Figure (1-3):** Cast in place box girder" (Chaitanya, 2019).

Prestress tendons embedded in the web concrete are used to prestress cast-in site box girder bridges. Tendons are frequently wrapped with parabolic profiles, as seen in Figure (1-4). Tendon profiles have a small cross-section in the center of the span and an increase in height at the ends. The tendon eccentricity (e) is the vertical distance between the bridge's neutral axis and the centroid of a post-tensioned tendon (Shah and Murudi, 2018). Compared to the other components, the box girder section requires less post-tensioning (Rodriguez, 2004). Suitable for curved bridges due to strong torsional stiffness from closed box action and ease of depth variation over the span. (Shah and Murudi, 2018).

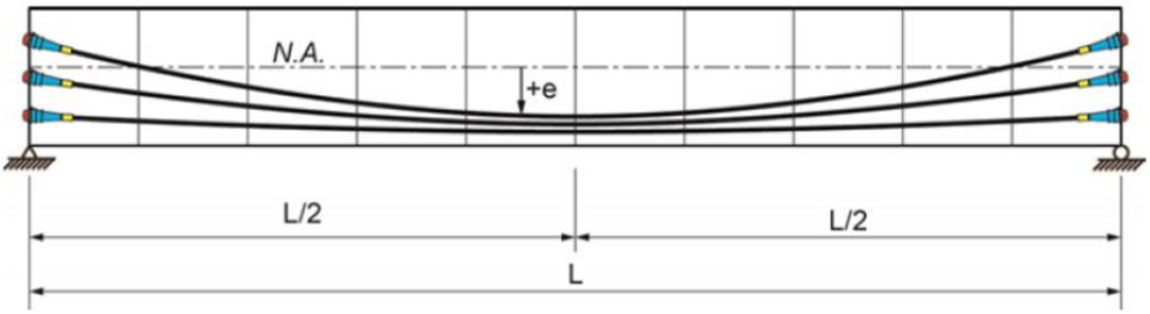



**Figure (1-4**) Pre-stress Tendon Layout for Simple Spans(Shah and Murudi, 2018)**.**

Tendons for single-span bridges are tightly packed toward the midpoint of the bridge web to increase tendon eccentricity. The tendons' spacing increases near the span's extremities to correctly position the post-tensioning anchorages. Post-tensioning anchorages are cast into diaphragms erected at the span ends. The solid concrete diaphragms transfer and distribute the tendon forces acting on the anchorages to the standard cross-section of the box girder as shown in Figures (1-5),(1-6). (Shah and Murudi, 2018).

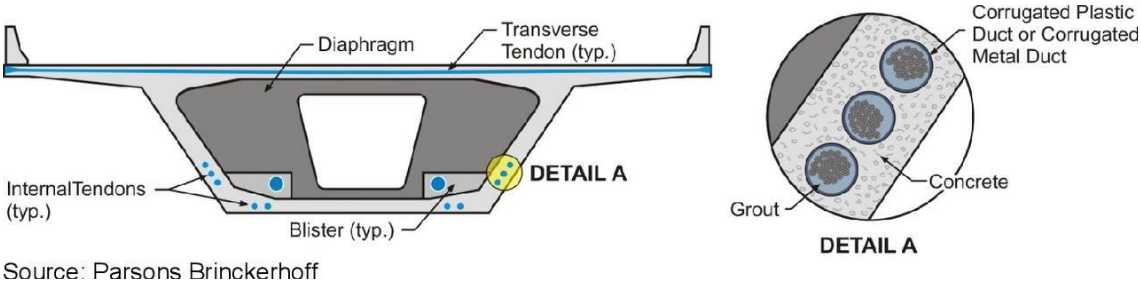



**Figure (1-5)** Tendon Locations within Box Girder Cross Section(Shah and Murudi, 2018).

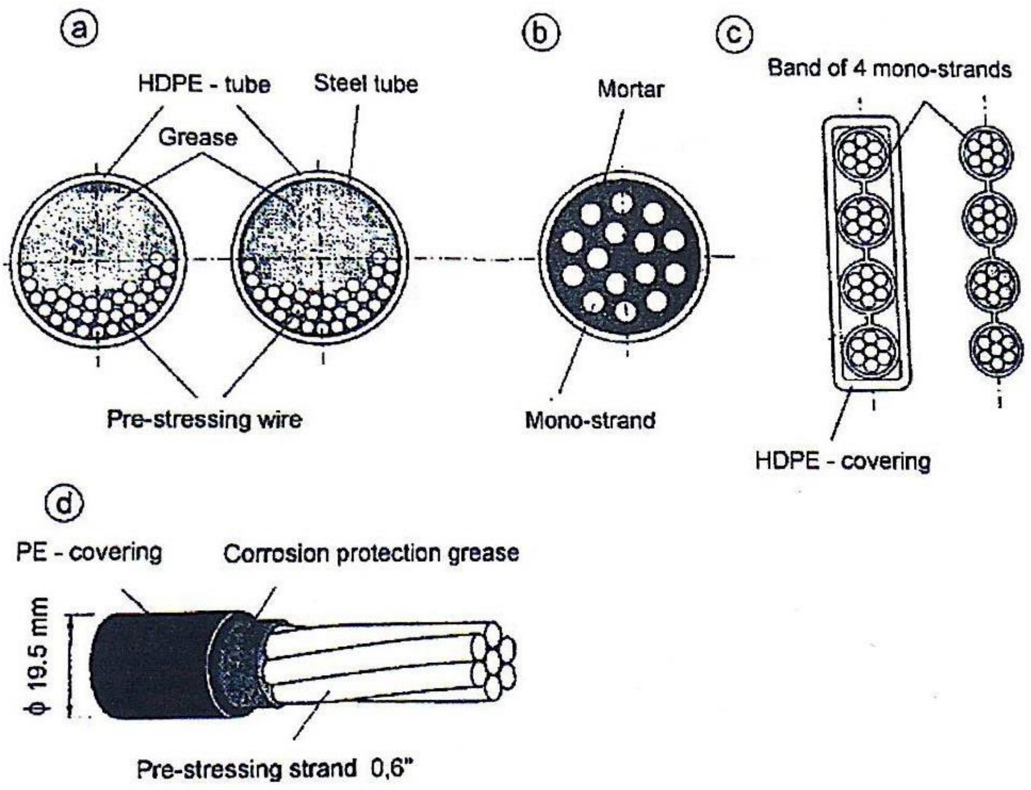



**Figure (1-6)** Cross Section of Prestressed Strand (Zilch and Penka 2014)**.**

## 1.3 Thermal Stresses on Reinforced Concrete Box Girders

Although bridges are designed to endure a hundred years, they are typically utilized for far longer periods. Thermal impacts occur on a daily, seasonal, or yearly basis, depending on the environmental conditions (Zhang *et al.*, 2017).

The increase and decrease of temperatures is one of the most critical factors influencing bridges. Temperature variations are influenced by the orientation of the structure, the material, the deck surface finishing layer, the structure dimensions, and the cross-section geometry. Bridges' performance may be influenced by the nonlinear thermal load caused by these phenomena(Abood, et a*l*., 2024).

These thermal loads can have complicated thermal effects on the structure's temperature field. Climate-related thermal influences on bridges are regarded as key design aspects. The safety of concrete may be influenced by stresses from limited thermal movements, which have been calculated to be of the same scale as those caused by traffic loads (Song, et *al* 2012).

Thermal actions are unique from other forms of loads because they are limited in nature. If these deformations are restricted, temperature changes induce thermal stresses, which may modify the stress field of the structure's length and cross-section as a result (Zhou and Yi, 2013) (Římal and Šindler, 2008).

Temperature variations in the vertical and horizontal axes produce additional bending moments. This makes more studies on thermal activities in bridge design fascinating (Emanuel, and Hulsey, 1978)( Kennedy, and Soliman., 1987).

In actuality, temperature fluctuations have a significant influence on bridges. Variations in uniform temperature cause significant overall length changes, as well as expansion and contraction. These length changes alter internal forces and structural dynamics, and the continual expansion and contraction may destroy crucial bridge members (Lu, et *al*., 2021).

When these deformations are restricted, temperature variations produce thermal stresses, which can lead to unexpected tensile fractures and, as a result, reinforcement corrosion(Zhou and Yi, 2013). As seen in Figure (1-7), temperature variations cause additional bending moments in the vertical and horizontal planes, respectively.

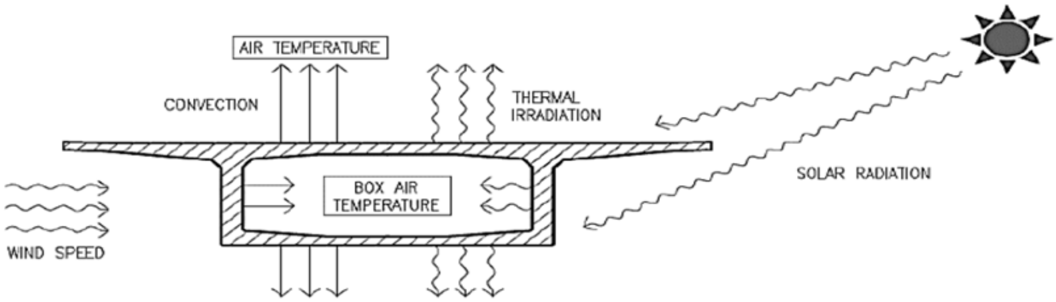



**Figure (1-7)** Environmental effects on bridge temperature change(Zhou and Yi, 2013).

Concrete bridge constructions are often subjected to thermal impacts as a result of their interaction with air temperature and solar radiation, which causes seasonal and daily temperature fluctuations in the structure. Seasonal variance is the highest predicted mean temperature change throughout the year. Concrete's low thermal conductivity causes temperature to fluctuate hourly from surface to interior regions, resulting in a nonlinear temperature distribution over the building. Thermal stress is always present in the girder section along its depth. Stress variations can lead to strain and deflection in bridge girder sections. The solution of the heat flow equation for various ambient circumstances is backed by (Emanuel and Lewis' 1981) experimental results, which establish critical design temperature gradients. Extensive research has been undertaken on the impact of temperature on concrete bridges in recent decades (1981, 2009, 1978). The nonlinear temperature distribution that occurs in concrete buildings in the early days after concreting creates tensile stress, which can also induce the cracking of young concrete.

## 1.4 Finite Element Modeling of Girders

The finite element technique is the most adaptable and appropriate numerical approach for meeting the majority of the following requirements: detailing, geometric and material behavior, loading characteristics, structural boundary conditions, and any significant interaction among them. To depict the structure, the finite element approach uses an assembly of discrete one, two, and three-dimensional elements. The structure is separated into elements that are only connected at their nodes, as Figure (1-8) showns, and they have an adequate amount of degrees of freedom

( Husain, 2007).

Recently, significant progress has been made in the creation of three-dimensional finite elements capable of reproducing the real nonlinear behavior of prestressed and reinforced concrete following crack formation. Thus, the finite element approach may be considered highly generic in applicability, and for challenging bridge deck issues, it is sometimes the only appropriate type of analysis ( Husain, 2007).

## 1.5 Objective and Scope of the Study

The main objective of this study is shown below:

1. Analysis findings are compared to experimental data, the load-displacement curve, and the deformed shape derived from prior experiments.
2. Study of the nonlinear behavior of reinforced concrete box girders, prestressed concrete box girders, and concrete box girders under the effect of thermal load using a nonlinear finite element model in three dimensions using the ANSYS computer program.

3. A parametric study was conducted to determine the effect location of thermal load, initial stress , area of tendons, and number of tendons which was applied to several parts of the concrete box girders.

## 1.6 Layout of the Study:

To meet the aims described above, this thesis is arranged into six chapters:

**Chapter one** offers an introduction , objective and Scope of this Study.

**Chapter two** provides a brief overview of prior work on finite elements. The approach for modeling pre-stressed box girders and RC box girders and investigating the influence of heat load on them.

**Chapter three** focused on the FE approach and the comparison of FE model predictions with experimental findings from laboratory-tested bridge models for various load instances in order to validate the FE model and offer information about the nonlinear response of prestressed concrete box girders.

**Chapter four** Verification Study of Reinforced Concrete Box Girder.

**Chapter five** contains parametric research that examines the effects of thermal load on reinforced concrete box girders, effects of heat load on prestressed concrete box girders, area of tendons, number of tendons, and effects of location of thermal load.

**Chapter six** provides the study's findings, recommendations, and future research directions.

التعليم العالي وزارة
والبحث العلمي
جامعة ديالى
كلية الهندسة

# تحليل العوارض الخرسانية الصندوقية مسبقة الاجهاد باستخدام طريقة العناصر المحددة تحت تأثير الاحمال الحرارية

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من قبل

محمد أحمد علي

بكالوريوس هندسة مدنية 2020

بأشراف

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