Seasonal Environmental Effects on Structural Behaviors of a Prestressed Double-T Slab

YITIAN LIANG and BRANKO GLIŠIĆ

ABSTRACT

By analyzing the temperature-strain relationships of structural components, key structural properties, such as the coefficient of thermal expansion (CTE), and boundary and continuity conditions of structures, can be assessed. However, these relationships can be influenced by non-structural factors such as variability of ambient environmental conditions, especially ambient temperature variations, which can obscure structural responses and complicate the identification of fundamental properties.

This study presents a preliminary study on the seasonal environmental effects on structural behaviors of a prestressed slab with a double-T cross-section through a series of static and dynamic loading tests conducted at different times of the year. Embedded long-gauge strain sensors are utilized to monitor temperature and strain continuously, capturing the slab's behavior under real-world environmental variations. By analyzing the temperature-strain relationships derived from on-site loading test measurements, the study aims to evaluate how different environmental temperatures affect the structural behaviors of the prestressed double-T slab, which can reflect the structural properties, such as CTE, boundary and continuity conditions.

The results demonstrate the ability of long-gauge sensors to accurately capture the slab's strain distributions under varying loading and temperature conditions. Seasonal effects are found to significantly influence the structural behavior of the slab, emphasizing the necessity of incorporating environmental factors into structural health monitoring practices. This research offers insights into the interplay between environmental conditions and structural properties, contributing to the development of more effective monitoring and management strategies for concrete structural components under seasonal environmental effects.

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INTRODUCTION

Prestressed precast concrete slabs with complex geometries, such as double-T cross-sections, are widely adopted in modern infrastructure due to their structural efficiency and ease of construction [1]. However, their in-service behavior is influenced not only by applied mechanical loads but also by environmental conditions, especially seasonal temperature variations [2,3]. These thermal effects can induce strain changes even in the absence of mechanical loads and may alter the apparent structural response under identical loading scenarios. Understanding the influence of ambient temperature on structural response is critical for accurate interpretation of monitoring data and long-term condition assessment. In particular, temperature-induced strain changes can obscure damage signatures, complicating the detection of early-age cracks, prestress losses, or stiffness changes. Conversely, temperature-strain relationships—if properly understood—can be leveraged to estimate key structural parameters such as the coefficient of thermal expansion (CTE), boundary restraints, and continuity conditions [4,5].

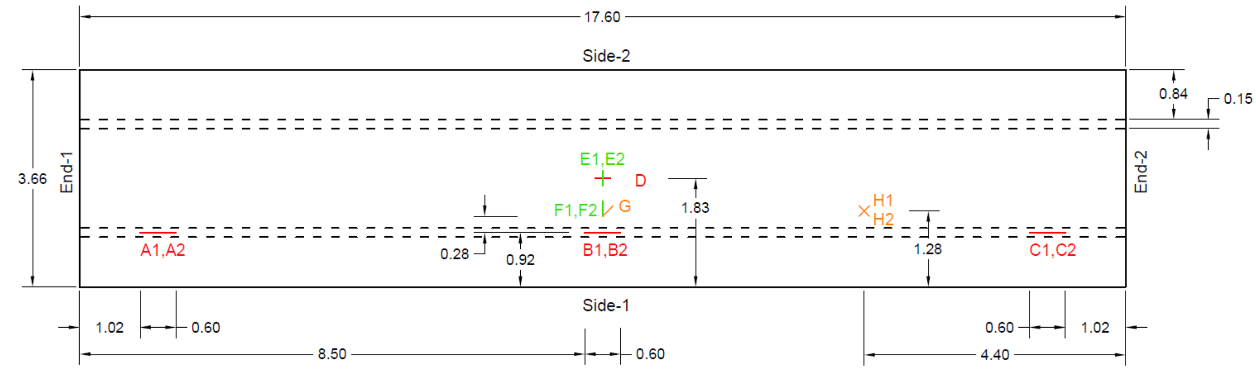
This study investigates how seasonal environmental changes affect the structural behavior of a real-world prestressed double-T slab in service at the Stadium Drive Garage, Princeton University. The slab is instrumented with embedded long-gauge fiber optic (FBG) sensors that continuously measure strain and internal temperature. Over the span of nine months, a series of static and dynamic loading tests were conducted under varying ambient temperatures, ranging from 8 °C to 24 °C, while keeping the mechanical loading configuration consistent.

The aim of this study is to examine how ambient temperature influences the structural response of a prestressed double-T slab under repeated loading, and to explore its implications for interpreting strain-based monitoring data. This paper presents preliminary observations on how the structural response of the slab evolves under repeated loading at different ambient temperatures. The analysis focuses on static strain measurements and the slab's first natural frequency as indicators of potential thermal effects on stiffness and boundary conditions. These results contribute to a better understanding of environmental influences on concrete structures and highlight the importance of accounting for seasonal variability in structural health monitoring (SHM) practices.

METHODOLOGY

Sensor Layout

The double-T slab of Stadium Drive Garage contains 14 embedded long-gauge FBG sensors, installed at locations denoted with A, B, C, E, F, D, G, and H, as illustrated in Figure 1. The sensors are mostly, but not only, installed in parallel and crossed topologies. For pairs of parallel sensors, such as sensors at locations A, B, C, E, F, the top sensor is denoted as "1" (e.g. "A1"), and the bottom one as "2" (e.g. "A2"). The gauge length of sensors at locations A, B and C was 60 cm (1'11.6"), and all the other sensors in the double-T slab had a gauge length of 25 cm (9.8"). The gauge length of sensors was determined using principles developed in Glisic 2011 [6].



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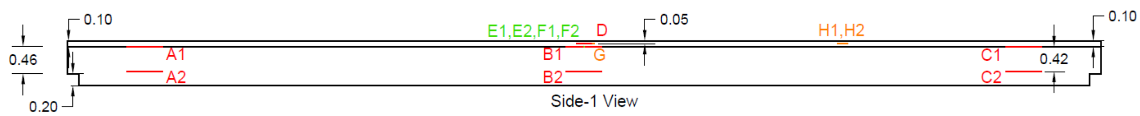

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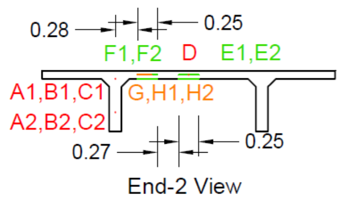

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Figure 1. Locations of embedded long-gauge FBG strain and temperature sensors in the prestressed double-T slab: (a) plane view, (b) elevation view, and (c) cross-sectional view; all dimensions are in meters [7].

Experimental setup

This study utilized data collected from FBG sensors embedded in a prestressed double-T concrete slab during four series of load tests conducted between Fall 2024 and Spring 2025. The tests were carried out under varying ambient temperatures, allowing for the evaluation of environmental effects on the structural behavior of the slab. A truck provided by Princeton University Facilities (Civil Engineering group), loaded with sandbags to achieve a total weight of approximately 10,000 lbs (4536 kg), was used to apply controlled loading. This loading magnitude was selected based on prior studies to generate measurable strain responses in the slab [8].

Each test series included both static and dynamic loading procedures. In the static load tests, the truck remained off the slab initially, then was driven into a predetermined position and held stationary for about one minute before being removed. The strain measurements continued for another minute after unloading. During these static events, sensor data was recorded at a sampling rate of 1 Hz. Figure 2 shows an image of the truck with its cargo bed loaded, positioned on the slab during one of the static test cases.

Figure 2. The truck on the slab in a static load test.

The dynamic tests involved driving the truck across the slab in the transverse direction at various speeds, with two runs performed per test series. Following each pass, the slab was left to vibrate freely for approximately one minute. Strain measurements during these tests were recorded at a higher sampling frequency of 100 Hz to capture dynamic responses.

Table I provides a summary of the ambient temperatures recorded during each of the four test series, along with the specific load cases used in static tests and the speed of the truck during dynamic tests. For cases labeled with a dash ("–"), the prefix "V" or "H" stand for "vertical" and "horizontal" respectively, referring to the orientation of the truck's centerline is along transverse or the longitudinal direction of the slab. The suffix describes the position of the rear wheels of the truck; "closer" means the side closer to the sensors, and "further" means the side further away from the sensors. Load cases are marked with a check "√" if they were included in a given test series, and a cross "×" if omitted.

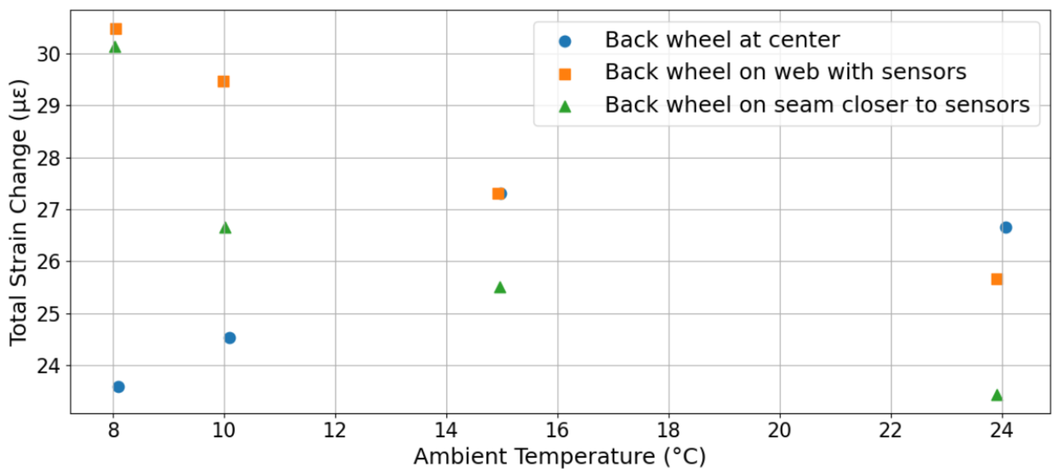
TABLE I. SUMMARY OF LOAD CASES IN FOUR TEST SERIES.

Load Case	Test 1 (15°C)	Test 2 (8°C)	Test 3 (10°C)	Test 4 (24°C)
V – center	√	√	√	√
V – web (w/ sensors)	√	√	√	√
V – web (w/o sensors)	×	√	√	√
V – seam (closer)	√	√	√	√
V – seam (further)	×	√	√	√
H – center	√	×	√	√
H – neighbor slab center (closer)	√	×	√	√
H – neighbor slab center (further)	×	×	√	√
Column test	√	×	√	√
Dynamic test (mph)	15, 20	22, 25	25, 29	28, 30

PRELIMINARY OBSERVATIONS

Figure 3 illustrates the relationship between ambient temperature and the total strain changes measured at two representative sensors, B1 and B2, for three different load cases. These three load cases were selected because they are the only ones with data collected under four distinct ambient temperatures (8°C, 10°C, 15°C, and 24°C). Sensors B1 and B2 were chosen for this analysis as they consistently recorded the largest strain changes among all embedded sensors in the slab, making them the most sensitive to load-induced deformation.

The strain responses reflect the structural behavior of the slab under vertical loading. Sensor B1, embedded near the top of the cross-section, consistently exhibits compressive strain, while sensor B2, located near the bottom, shows tensile strain, indicating that the slab bends downward under the applied loads. Notably, across all three load cases, both sensors show a trend of decreasing strain change with increasing ambient temperature. This behavior may be attributed to thermal expansion effects that improve contact between the slab and adjacent structural components (e.g., supports or connections), thereby altering the slab's boundary conditions and constraining its deformation under applied loads.



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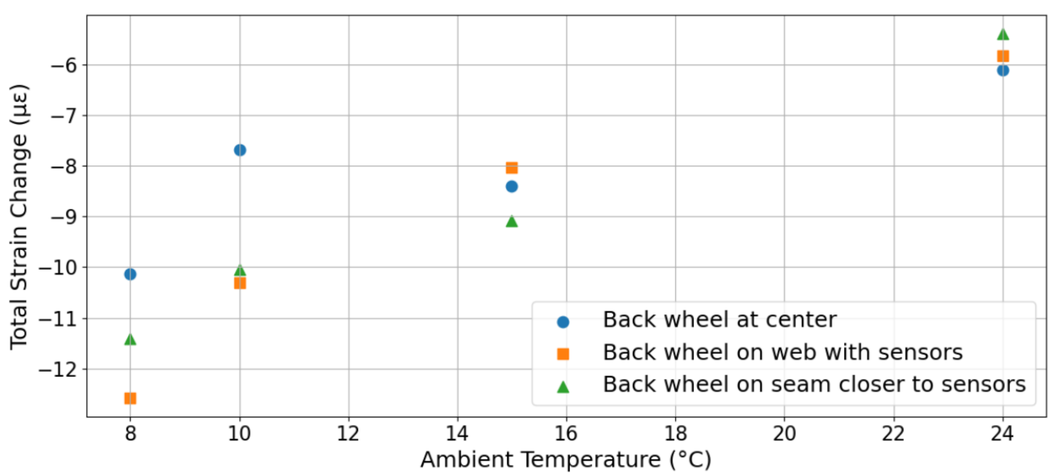

(b)

Figure 3. Total strain changes versus ambient temperature under three different load cases measured at sensors (a) B2 and (b) B1.

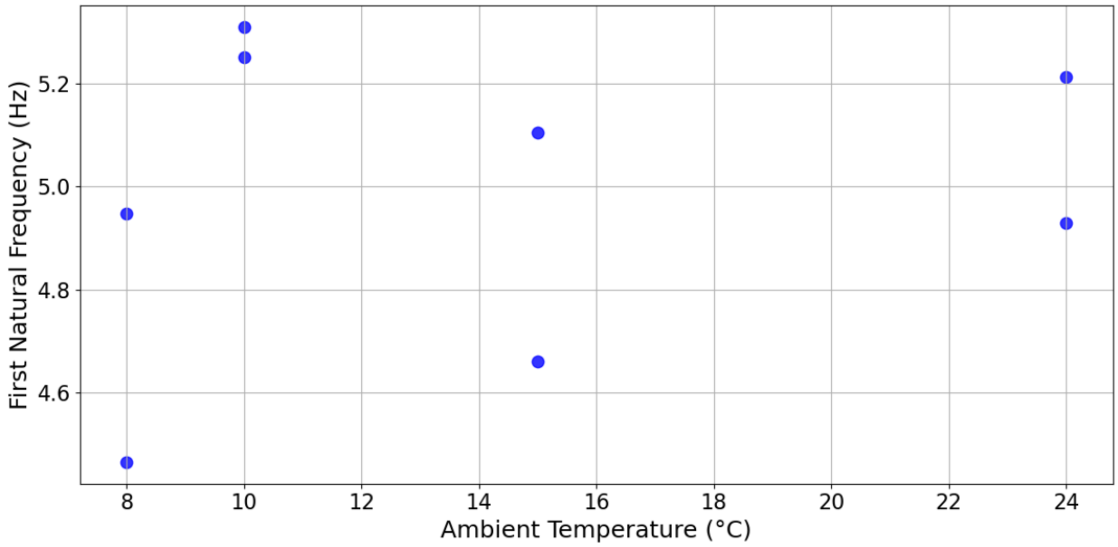

Figure 4. First natural frequency of the slab versus ambient temperature.

Figure 4 presents the first natural frequency of the slab, extracted from multiple dynamic tests conducted at ambient temperatures ranging from 8°C to 24°C. Despite the significant temperature variations, the natural frequencies remain relatively stable, with no clear trend observed across the different conditions. This suggests that ambient temperature has a limited effect on the dynamic stiffness and overall global behavior of the slab in terms of its first mode of vibration.

CONCLUSIONS

This study analyzes the strain responses of a prestressed precast concrete slab embedded with FBG sensors under repeated localized loading at varying ambient temperatures. The results demonstrate the effectiveness of the monitoring system and the loading configuration. Clear trends were observed in the total strain changes in static tests. Importantly, the magnitude of total strain changes decreases with increasing temperature, suggesting that the slab becomes more constrained at higher temperatures, potentially due to thermal expansion tightening the contact with surrounding structural components. In contact, dynamic test results show that the slab's first natural frequency remains largely unchanged across different ambient temperatures. These findings emphasize the critical role of temperature in interpreting structural responses and reinforce the importance of incorporating thermal effects in condition assessment and long-term monitoring.

Future work will focus on further examining the principles underlying the observed temperature-dependent strain variations, including the potential influences of thermal-induced stiffness changes and boundary conditions. Additional analysis will aim to quantify these relationships to better interpret long-term monitoring data. Moreover, dynamic analyses will also be expanded to explore the evolution of global structural behavior across seasonal cycles, supporting more robust long-term condition assessments.

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