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# Structural Behaviors of Prestressed Double-T Slab under Loadings with Seasonal Effects

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ABSTRACT: Understanding the effects of temperature on structural behavior is critical in structural health monitoring (SHM), especially for prestressed concrete components with complex geometries due to their complicated internal strain distributions. Temperature-strain relationships in structural components can offer valuable insights into various structural properties, such as the coefficient of thermal expansion (CTE), and boundary and continuity conditions of structures. However, these relationships can be influenced by variability of ambient environmental conditions, especially ambient temperature variations, which can create thermal gradients and complicate the interpretation of relationships and identification of structural properties.

This study presents a preliminary study on the structural behaviors of a prestressed slab with a double-T cross-section through a series of static and dynamic loading tests conducted across four seasons, with ambient temperatures ranging from 8°C to 24°C. The proposed approach utilizes long-gauge strain sensors embedded within the slab to continuously capture strain and temperature data. By analyzing the temperature-strain relationships derived from on-site loading test measurements, the study aims to evaluate how the structural behaviors of the prestressed double-T slab, which can reflect the structural properties, such as boundary and continuity conditions, change under different environmental temperatures.

The preliminary results show clear variations in strain changes for the same loading condition under different temperatures. These variations suggest that environmental temperatures and thermal gradients could affect load response and boundary restraints. Furthermore, the findings demonstrate that the embedded long-gauge strain sensors effectively capture the temperature changes and strain distribution under the loadings, enabling the assessment of structural behaviors of the slab with seasonal effects. This research highlights the importance of accounting for environmental factors in structural health monitoring and provides new perspectives for understanding and predicting the behavior of structures with complex geometrical properties (e.g., double-T slab) under varying conditions.

KEY WORDS: Prestressed concrete slab; Thermal behavior of structures; Temperature-strain relationship; Long-gauge fiber-optic strain sensors; Complex geometrical and boundary conditions; Structural health monitoring.

## 1 INTRODUCTION

Prestressed precast concrete components with complex cross sections, such as double-T slabs, are widely used in modern construction due to their high load-carrying efficiency [1]. However, their structural behavior is influenced not only by applied mechanical loading but also by environmental factors, most notably temperature [2,3]. Seasonal fluctuations in ambient temperature can cause significant strain variations within these components, even in the absence of mechanical loading, and complicate the interpretation of measurement data used in condition assessment and damage detection. In addition, temperature-strain relationships can provide valuable insights into material properties (e.g., help evaluate thermal expansion coefficient), restraint and boundary conditions, and the overall stiffness behavior of structural systems [4,5]. Understanding how these relationships evolve under different environmental conditions and loading scenarios is essential for assessing in-situ structural behavior and for developing reliable long-term monitoring strategies.

This project is developed based on the real-life case study. More specifically, it is based on observation of the structural behavior of a prestressed double-T slab located in the Stadium Drive Garage, Princeton University, with a particular focus on the influence of seasonal temperature variations. The slab is instrumented with long-gauge Fiber Bragg Grating (FBG) sensors embedded within the concrete during construction. These sensors allow for simultaneous, continuous measurement of strain and internal temperature over extended periods.

To explore how environmental conditions influence the load response, four series of load tests were conducted over a period of nine months at different environmental temperatures. Each test series included static loading with various load cases, and dynamic testing. While the mechanical load applied during each test series remained similar, the environmental temperature varied significantly between tests, ranging from 8°C to 24°C. This variation provides a unique opportunity to assess the interaction between thermal conditions and mechanical response in a controlled yet realistic setting.

The aim of this study is to observe how strain responses in a prestressed double-T slab vary under similar loading scenarios across different ambient temperatures, and to explore the potential for identifying temperature-related effects on structural behavior. Preliminary observations confirm that the environmental temperature affects the measured strain distribution under mechanical load.

The originality of this study lies in the following aspects. It combines seasonal on-site testing under varying ambient conditions with embedded long-gauge FBG, which captures internal strain and temperature responses that surface-mounted sensors could miss. In addition, the study focuses on a prestressed double-T slab with complex boundary conditions, a

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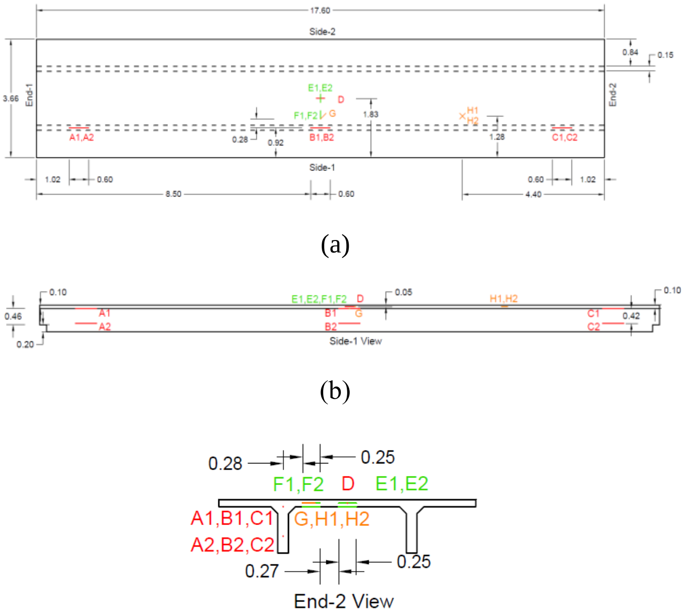
structural form that presents significant challenges for SHM yet has been underrepresented in previous literature.

While full analysis is ongoing, this extended abstract summarizes the current progress by describing the instrumentation and load configurations and presenting preliminary observations of temperature-influenced structural behavior.

## 2 METHODOLOGY

### *2.1 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].




(a)

(b)

(c)

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].

### *2.2 Experimental setup*

The measurement data analyzed in this paper was collected from FBG sensors in the double-T slab during four series of load tests conducted between fall 2024 and spring 2025 at different environmental temperatures. These tests were performed using a truck provided by the Princeton University Facilities (Civil Engineering group), loaded with sandbags in the cargo bed to achieve a target weight of 10,000 lbs (4536 kg). This weight was selected to incur statistically significant strain, according to the results of previous research on the slab [8]. Each test series included two types of load tests: static and dynamic. This paper focuses on results of static tests only, while dynamic tests are described only for the purposes of the completeness of presentation. In the static tests, the procedure began with the beam unloaded for approximately one minute. The truck was then driven onto a designated position on the beam and held stationery for another minute before being removed, after which the beam remained unloaded for an additional minute. During these static tests, sensors recorded strain at a rate of 1 hertz (Hz), or one measurement per second. An example of the truck with its cargo bed loaded with sandbags positioned on the beam during a static test is shown in Figure 2.

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

In the dynamic tests, the truck was driven across the width of the slab at variable speeds twice during each test series. After each impulse, the slab was allowed to vibrate freely for approximately one minute afterward. During these tests, the sensors measured at a rate of 100 Hz.

Table 1. 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 |

Table 1 shows the environmental temperatures during four test series, all load cases each test series contains, and the speed of the truck during dynamic tests. For the load cases with the dash sign, the “V” and “H” before dash stand for “vertical” and “horizontal” respectively, which mean whether the centerline of the truck is along the length or the width of the slab; after the dash is the position of the rear wheels of the truck; “closer” means the side closer to the sensors, and “further” means the

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side further away from the sensors. The tick mark "√" means the test series contains marked load case, and the cross "×" means the test series does not contain the load case.

## 3 PRELIMINARY OBSERVATIONS

Figure 3 presents the strain response recorded by FBG sensors embedded in the slab during Test2 with the load case "V – center". The total strain changes Δε are plotted over time, with different colored lines representing individual sensors. Notably, sensors B2 shows significantly larger responses compared to others, due to its proximity to the applied load and its position at the midspan of the slab. This observation supports the effectiveness of the sensor network in capturing localized events while providing spatial context for interpretation.

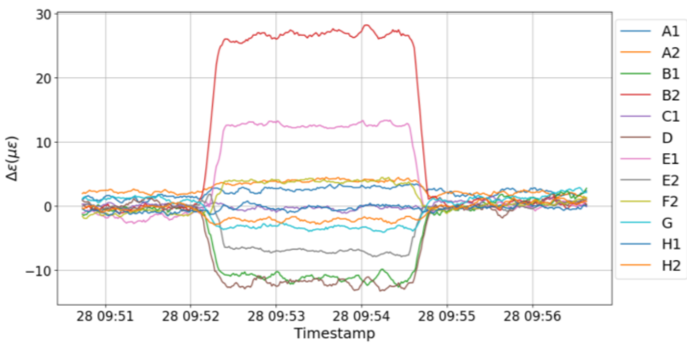


Figure 3. Total strain changes from slab-embedded FBG sensors during a static test.

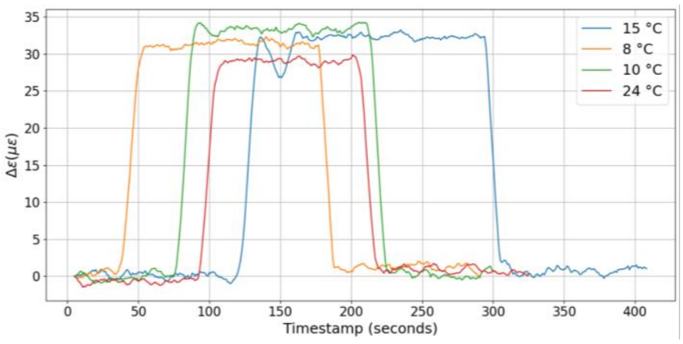


Figure 4. Total strain changes of sensor B2 under the same load case but at different ambient temperatures.

Figure 4 compares the strain measurement from one specific sensor (sensor B2) under the same type of load case but conducted under different ambient temperature conditions. Four curves represent four separate tests carried out when the slab was exposed to 8 °C, 10 °C, 15 °C, and 24 °C. Although all tests exhibit a similar response pattern (a rapid increase in strain during loading and a drop afterward), the magnitude of the peak strain differs across temperature conditions. This variation suggests that ambient temperature influences the sensor response—potentially due to changes in material stiffness, temperature gradient along cross section, or boundary restraint conditions. For example, the decrease in response with increase of temperature, for temperature higher than 10°C may reflect thermal expansion effects that result in higher stiffness of restrained slabs; inverse behavior for temperature lower than 10°C may indicate change in boundary conditions or interaction at connections. Yet combined effects can be in play in both cases.

These preliminary findings highlight two key observations: (1) the sensor network effectively captures localized strain patterns, and (2) environmental temperature influences the strain response, even under consistent loading scenarios. These effects will be further examined through more comprehensive analysis in future.

## 4 CONCLUSION AND FUTURE WORK

This study assesses the strain changes of a prestressed precast concrete slab with embedded FBG sensors under repeated localized loading and varying ambient temperatures. Through a series of static and dynamic load tests conducted across different seasons, it was observed that the same loading configuration caused different strain changes under varying ambient temperatures. The tests confirmed the effectiveness of the monitoring system and loading configuration. Furthermore, these preliminary observations highlight the significance of temperature as a factor affecting structural response and underline the importance of accounting for 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, the study will be extended to evaluate the dynamic behavior of the structure under different environmental temperatures to gain deeper insights into the stiffness evolution and structural performance with seasonal effects.

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