Engineering Structures 155 (2018) 209–221

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Temperature-driven structural identification of a steel girder bridge with an integral abutment

Brittany Murphy[*], Matthew Yarnold

Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843, United States

ARTICLE INFO

Keywords:
Structural identification
Thermal analysis
Finite element modeling
Steel girder bridge
Temperature
Monitoring
Integral abutment

ABSTRACT

The Tennessee Department of Transportation (TDOT) visually detected recurring structural damage with one of their steel girder bridges in eastern Tennessee, USA. These issues prompted an investigation into the source of the damage. TDOT approached the structural research team in Tennessee Tech University's Civil and Environmental Engineering Department with what presented as damage related to thermal effects acting on the Anderson County Route 61 Bridge. In the presented study, temperature-driven structural identification is employed on the Route 61 Bridge to assess the structural damage and determine potential causes of such deterioration. An element-level, finite element model is created to provide insight regarding the bridge behavior. The bridge is field instrumented with monitoring equipment to quantify the bridge responses to daily thermal loads. The quantitative results are then used to calibrate the model and represent the bridge in its current condition. The root cause of the damage is identified through multiple numerical simulations and recommendations are provided for the long-term rehabilitation and preservation of the structure. Overall, the study contributes knowledge regarding the thermal behavior of steel girder integral abutment bridges including expansion/contraction movement, built-up strains/stresses, and potential damage produced by thermal loads. This study also provides illustration of an effective temperature-driven structural identification approach for evaluation of these types of structures.

1. Introduction

In recent years, several studies and methodologies have been utilized to evaluate girder bridges. In particular, research has been specifically directed toward integral abutment bridges (IABs). IABs minimize maintenance costs due to the lack of multiple expansion joints. As a result, many structures of this type have been constructed over the past few decades. The overall functionality of these bridges has shown to be promising, but research has been crucial for better comprehension of IAB behavior. To date, research endeavors have explored many components of IABs through thermal-induced testing.

Thermal-induced testing has many benefits. This type of testing can be conducted continuously over extended periods of time and record structural responses through a bridge's changing environments. Thermal-induced testing can be designed as self-sustaining with little intervention needed from researchers. Logistically, these tests typically require minimal data storage and the monitoring equipment used is relatively inexpensive. In addition, the thermal-induced responses (e.g. strains and displacements) are typically substantial and relatively easy to measure. However, thermal-induced testing also has several drawbacks. For short-span bridges, structural responses from live loads can interfere with thermal responses making them more difficult to separate. Another disadvantage is that the results from these tests are generally not readily available as the tests require long monitoring periods to collect adequate amounts of data.

Despite these challenges, extensive thermal-induced testing has been conducted. Several studies have investigated the effects of temperature on backfills and abutments of these structures [1,2]. Others have primarily focused on the effects that thermal expansion has on the pile behavior [3]. Research efforts have also investigated the connection characteristics between the bridge and abutment within the integral abutment [4]. Broader studies have analyzed IABs in their entirety rather than focused on particular components. One research effort investigated the effects length and skew of the bridge, abutment and pier offsets, and temperature gradients have on the thermal expansion of IABs [5]. Another researcher studied the thermal movements and stresses developed in these bridges and their effect on bearing and expansion joint placement [6]. Although considered recent, several IABs have undergone extensive testing and have started to collect information on long-term structural behavior [7].

---

[*] Corresponding author.
E-mail addresses: brmurphy@tamu.edu (B. Murphy), myarnold@tamu.edu (M. Yarnold).

https://doi.org/10.1016/j.engstruct.2017.10.074
Received 15 May 2017; Received in revised form 19 September 2017; Accepted 31 October 2017

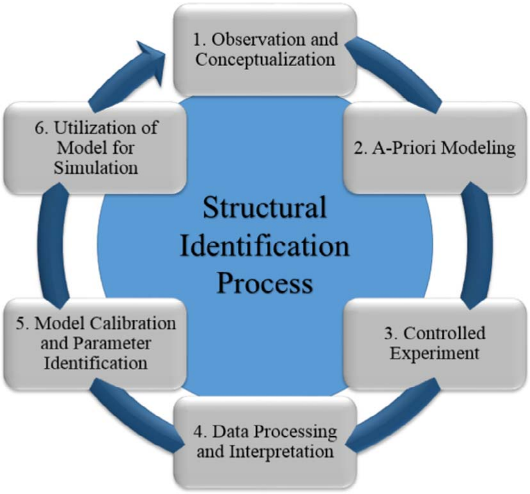

Fig. 1. Structural identification process (St-ID).

Temperature-induced testing has also been utilized to identify causes of deterioration to a structure [8,9]. Results from thermal-induced testing can be highly sensitive to many changes in geometric or material properties of structural systems and have been used specifically as damage indicators [10–12]. Damage is defined as unintentional changes to physical properties, such as boundary conditions and structure continuity, that affect a structure's behavior [13,14]. Damage detection can be achieved by using a temperature-driven approach to the well-established structural identification (St-ID) process [15], shown in Fig. 1, to evaluate the bridge and divulge information about its behavior.

2. Concept and approach

Ultimately, the St-ID process uses model calibration to compare measured responses to finite element model values and optimize the model to depict the current bridge behavior. The measured responses can be instigated by a variety of methods including vibration, live loads, or thermal loads. Conventional vibration testing has difficulties identifying boundary/continuity condition parameters in the field due to the lack of sensitivity, environmental effects, and other logistical challenges. [16,17]. Live load testing primarily divulges information regarding load-carrying capacity and load ratings [18], load distribution [19,20], or composite action between the deck and superstructure [21]. This type of testing provides little information regarding translational movement at boundary conditions. Temperature-driven St-ID aims to address these shortcomings. For temperature-driven St-ID, model calibration is completed by using a temperature-driven signature from the measurements collected from the monitoring system (Measured Temperature-Driven Signature) and various signatures generated from the finite element model (Model Temperature-Driven Signatures). A temperature-driven signature is simply a set of data that defines the thermal bridge behavior for a particular set of parameters (i.e. temperature change, boundary condition). Once the model has been optimized, it is then used to perform simulations that deduce information about the structure.

The first step of temperature-driven St-ID is “Observation and Conceptualization” in which any background information about the structure is gathered, whether through original plans, rehabilitation drawings, inspection reports, site visits, or various other methods of observation. In the next step “A-Priori Modeling”, this knowledge is used to develop a preliminary finite element model of the structure in “ideal” or “as designed” conditions. Then, a controlled experiment is designed and implemented on the structure in the “Controlled Experiment”. For a temperature-driven study, daily thermal loads are used to excite the structure, and measurable responses such as strains, displacements, or rotations are collected. In “Data Processing and Interpretation”, the raw data is quality checked and processing is performed such as zeroing, filtering, and averaging. The “Measured Temperature-Driven Signature” is then determined. In “Model Calibration and Parameter Identification”, the “Model Temperature-Driven Signatures” are determined from numerous model simulations. Model calibration identifies an optimized model that accurately represents the behavior of the bridge. Finally, in “Utilization of Model for Simulation”, the optimized model is used to analyze the bridge and its behavior in reality. Recent temperature-driven St-ID studies have successfully been performed in the laboratory [22], on steel girder bridges [23], and long-span bridges [24–26]. In order to complete a temperature-driven structural analysis of a bridge, an extensive knowledge of thermal behavior is required. An insight into some of this knowledge is described/provided below.

Like most materials, bridge materials such as steel, concrete, and asphalt expand and contract in response to thermal “loads”. Material properties, structure geometry, and restraints imparted by boundary conditions heavily influence deflections, stresses, and strains that occur as results of such loading. A critical aspect of thermal behavior is that the response is a combination of an unrestrained portion and a restrained portion (illustrated further below).

The physical make-up of these materials allows for unique rates of heating/cooling (quantified as thermal inertia) as well as expansion/contraction (quantified as coefficient of expansion) for each material. The coefficient of thermal expansion (α) directly relates how much the material expands or contracts, thus it affects the stress or strain in particular members of the bridge. Another important factor that affects the strain or stress in those members is the boundary conditions of the bridge. Boundary conditions can vary in extent of impeded motion; therefore, it is possible to have boundary conditions that are unrestrained, partially restrained, or fully restrained. If the structure is assembled in such a way that prevents movement from thermal effects, stress accumulates within the members.

Fig. 2 provides an illustrative example of a partially restrained W10x54 beam, subjected to a uniform temperature change (ΔT), which uses a spring to define the extent of restraint at one end of the member. The total displacement (δ_T) is a combination of the unrestrained displacement (δ_U) and the restrained displacement (δ_R) and can be calculated as shown in Eq. (1).

$$\delta_T = \delta_U + \delta_R = \alpha * \Delta T * L \tag{1}$$

The restrained displacement (δ_R) is the portion that produces stress in the member (δ_U produces no stress). This restraint occurs as a result of the spring support exerting a longitudinal axial force (P) on the member. Therefore, δ_R can be calculated as shown in Eq. (2), where A represents the cross-section area and E represents the modulus of elasticity.

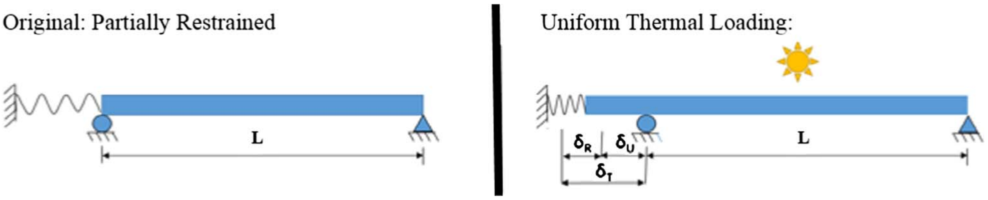

Fig. 2. . Example of partially restrained W10x54 beam subjected to uniform thermal loading.