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Field monitoring study of an integral abutment bridge supported by prestressed precast concrete piles on soft soils

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ABSTRACT

Integral abutment bridges (IABs) have been constructed during the past several decades around the world. The purpose was to eliminate expansion joints and minimize joints induced problems. Even though IABs have been widely accepted due to the satisfying performances, yet they have not been largely applied in practice. Some of the reasons may be attributed to the uncertainties of these bridges under different loading conditions, especially the daily and yearly varying temperature effects. In this paper, the behavior of the first IAB constructed on the soft soil condition in Louisiana is discussed. A field monitoring program is introduced and the measured results from 08/11/2011 to 03/15/2014 are presented. The field monitoring program leads to the following observations, (1) significant seasonal and daily temperature variations are observed on the bridge slabs but within the AASHTO temperature design specification; (2) the displacements and rotations of bridge components are well correlated with the temperature variations; (3) the thermal stresses generated in the slabs may exceed the allowable material cracking capacity; (4) the soil behavior behind the abutments is complicated and long term monitoring program is needed; (5) the integral abutment primarily behaves in translation rather than rotation; and (6) the pile inflection (zero bending) point is observed and the strong and weak axels bending are all important due to the bridge skewness.

1. Introduction

Expansion and contraction are two basic responses of bridges induced by temperature variations. Traditionally, a relief system, consisting of expansion joints, bearing supports, or other devices, are designed to accommodate these movements. After years of services, however, this system, especially the expansion joint, may become one of the vulnerable elements affecting the sustainability of bridges [18,21].

Bridge engineers have been trying to eliminate expansion joints whenever possible; and the concept of integral bridges without joints was inspired. Generally speaking, integral abutment bridges (IABs) can be categorized into three types [24]: (1) a full IAB, as discussed in this paper, refers to a single or multi-span bridge as shown in Fig. 1. The superstructure of the bridge, i.e., concrete slabs, prestressed concrete beams, steel girders, and approach slabs, is casted monolithically with a stub type abutment and supported on a row of piles; (2) a semi-integral bridge is similar to the full IAB, but the abutment is not rigidly connected to the substructure; and (3) a deck-extension bridge extends its deck slab over the abutment into the approach pavement, but the main beams or girders are not fixed on the abutment. In an integral configuration, expansion joints are eliminated and the corresponding joint-related issues can be minimized. However, a new challenge arises since the horizontal movements from the superstructure are transferred to the substructure, which have to be well accommodated through the soil–structure interaction or other special designed mechanisms.

The benefits of IABs have been widely accepted in the past several decades around the world. Survey has been conducted on the construction experience of IABs in American [16] and European countries [4,25], where many similarities were observed even though significant differences existed in some aspects. Field monitoring study methods have been adopted to investigate and justify the design and construction concepts, including (a) the maximum allowable design criteria (e.g., total and individual bridge's span lengths and skews); (b) the structure design parameters (e.g., orientations of the pile, abutment, and wingwall); (c) the soil–structural interaction behaviors (e.g., between the soil–pile, abutment-backfill, and approach slab-backfill); (d) the joint connection effects (e.g., at the interfacial locations between the abutment-deck-girder, abutment-pile cap, approach slab-abutment, and intermediate pier-girder); (e) the stress relief

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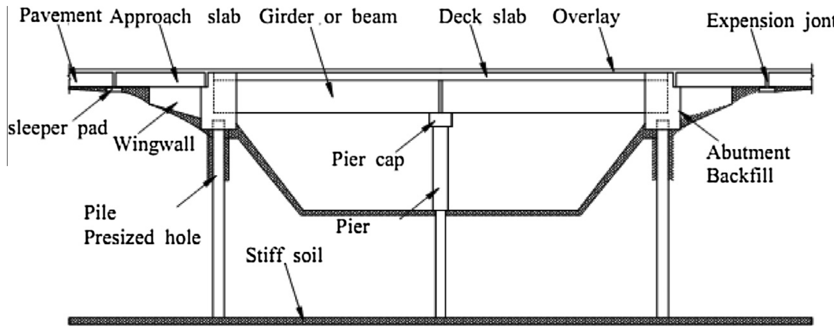

Fig. 1. Schematic view of a full integral abutment bridge (IAB).

mechanisms (e.g., diameters, depths, and filling materials of the pre-sized holes surrounding the piles, and the compacting degree of the backfill materials behind the abutments); and (g) the long term effects (e.g., the temperature, shrinkage, creep, and steel relaxation) [3,13,2,10,11,15,5,8,12,19,7,25,14,20,26,4,6].

In the state of Louisiana, no full IABs have ever been built before the year of 2011. The reasons are partly due to the lack of references from the previous studies regarding on the behaviors of bridges on the unique soil conditions in Louisiana. To this end, the present paper reports the field monitoring program from 08/11/2011 to 03/15/2014 for the first full IAB, the Caminada Bay Bridge, designed by the Louisiana State Department of Transportation and Development (LADOTD). This bridge also has some special features that have not been focused in the previous investigations on integral bridges, such as the long continuous slab spans, deep precast prestressed concrete piles, shallow integral abutment, and very soft soil conditions. Based on the monitoring results, the temperature induced effects on the superstructure and substructure of such a bridge are demonstrated. Specifically, (1) significant seasonal and daily temperature variations are observed on the bridge slabs but within the AASHTO temperature design specification; (2) the displacements and rotations of bridge components are well correlated with the temperature variations; (3) the thermal stresses generated in the slabs may exceed the allowable material cracking capacity; (4) the soil behavior behind abutments is complicated and long term monitoring program is needed; (5) the integral abutment primarily behaves in translation rather than rotation; and (6) the pile inflection (zero bending) point is observed and the strong and weak axels bending are all important due to the bridge skewness.

2. Bridge descriptions

The Caminada Bay Bridge is located at the Grand Isle, LA (29°15′48″N, 89°57′24″W), about 160 km to the south of New Orleans, LA. While the total length of the bridge is 1202 m (3945 ft), the monitoring program is conducted on the first eleven spans, as shown in Fig. 2, including a 3 m (10 ft) sleeper slab, a 12 m (40 ft) approach slab, a 91 m (300 ft) continuous concrete slab, and also the abutment, bent, pile, and soil. The width of the bridge is 15 m (50 ft) consisting of two 6.4 m (21 ft) lanes and a 2 m (7 ft) sidewalk on the northern side. For the parts that are monitored, the slabs are fully integrated with the first bent (Bent1) at the left end, simply supported on the eleventh bent (Bent11) at the right end, and rigidly connected with all the interior bents in between, where the expansion and fixed connection joints are designated as “E” and “F” in Fig. 2. Each bent is rigidly supported on a single row of four prestressed precast concrete (PPC) piles. The soil types, referred to the boring log information near Bent1, can be approximately subdivided into two layers, including a medium sandy soil layer from the ground to the depth of 18.9 m (62 ft), and a medium clay layer through the rest of the depth. The materials and the corresponding properties for this Caminada Bay IAB are listed in Table 1.

3. Instrumentations

Bridge Diagnostics, Inc. (BDI) was contracted by the Louisiana Transportation Research Center (LTRC) and Louisiana State University (LSU) to install the bridge monitoring system. In this project, a total of 81 instruments were applied on the bridge, as listed in Table 2, including the vibrating wire strain gages, vibrating wire tiltmeters, vibrating borehole wire extensometers, vibrating wire pressure cells, piezometers, and vibrating wire thermistors. The large application of vibrating wire gages is due to their good performances, without drifts, for the long-term monitoring. Meanwhile, each sensor is provided with an extra temperature thermistor so that the temperature information of the bridge elements can be simultaneously obtained.

3.1. Superstructure instrumentation

For the superstructure, a total of 22 sensors, with 14 embedded sisterbars and 8 surface strain gages, as shown in Fig. 3, were applied on the 46 cm (18 in.) depth concrete deck. They were adopted to measure the positive and negative strains due to the temperature changes. Specifically, the embedded sisterbars were placed at the rebar locations before the pouring of concrete with 8 cm (3 in.) above the bottom surfaces on the approach slab, Span1, Span3, and Span5, and with 5 cm (2 in.) below the top surfaces on the Bent1, Bent2, and Bent5. The surface strain gages, otherwise, were mounted under the bottom surfaces from Span3 to Span6 after the completion of the concrete pouring.

3.2. Substructure instrumentation

For the substructure, a total of 59 instrumentations were installed as shown in Fig. 4. The monitoring program related to sensors and instrumentations in the abutment and the foundation of the bridge was conducted by the research groups of Drs. G.Z. Voyiadjis and K.A. Alshibli at LSU. Some of the important information is briefly described here for the convenience of readers, and the detailed information can be referred to the report by Voyiadjis et al. [23]. For example, (a) 32 sisterbars were installed at the four corners of two 24 m (80 ft) long PPC piles at the easternmost of Bent1 to measure the pile strains. The distances from the sisterbars at each sensor sections to the bottom surface of Bent1 were 1.2 m (4 ft), 3.7 m (12 ft), 6.1 m (20 ft), and 8.5 m (28 ft), respectively; (b) 2 tiltmeters were attached at the middle section of the 1.2 m (4 ft) high Bent1 and Bent11 to record the bents’ rotations; (c) two rows