Field Monitoring of Concrete Piles
of an Integral Abutment Bridge

Khalid Alshibli[1(✉)], Andrew Druckrey[1], and George Z. Voyiadjis[2]

[1] University of Tennessee, Knoxville, TN, USA
[2] Civil and Environmental Engineering, Louisiana State University,
Baton Rouge, LA, USA

Abstract. Integral abutment bridges (IABs) are a cost-effective design method for bridges. Recently, Louisiana Department of Transportation and Development (LA-DOTD) constructed their first two IABs; one was supported by HP steel piles driven in clayey soil while the other was supported by pre-stressed precast concrete (PPC) piles driven into fine sand deposit. The use of PPC piles has long been recognized as a good option for Louisiana bridges. However, there are concerns that the rigidity of the piles driven in sandy soils might cause excessive stresses in the bridge superstructure. This paper presents the instrumentation plan of two 36 in (914.4 mm) square PPC piles and the bent-soil interaction. Sisterbar strain gauges were attached to the pre-stressing strands in the piles along with nine pressure cells that were attached to the face of the bent supporting the piles. The bridge deformations were mainly controlled by the piles' rigidity, soil resistances surrounding the piles, and connection behaviors between the pile-bent. Based on the observed temperature effects, the design of the piles of the Caminada Bay Bridge is very conservative. The piles experienced very low bending moments and very small amount of pressure on the backfill soil.

1 Introduction

Integral abutment bridge (IAB) systems have become a cost-effective alternative in the last two decades. They are constructed without deck joints, particularly at the abutments. IAB have also been referred to as integral, jointless, rigid-frame, and U-frame bridges. First built in the United States in the 1930s, by the 1990s, IABs were extensively used worldwide. IABs can be single or multiple spans, offer several advantages over conventional structures, and are currently used in more than 30 US states and Canadian provinces (e.g., Wolde-Tinsae and Greimann 1988; Russell and Gerken 1994; Kunin and Alampalli 2000; Arockiasamy et al. 2004) and in other countries. Benefits offered by integral bridges include reduced initial costs, lower long-term maintenance expenses, elimination of problematic expansion joints and bearings, less deterioration, lower impact loads, improved riding quality, simple construction procedures, and structural continuity to resist overloads. The disadvantages of such construction include subjecting the superstructures to large secondary stresses caused by the response of continuous superstructures to thermal and moisture changes. These cyclic movements and stresses must be addressed at the bridge abutment. US Federal Highway Administration (FHWA) is promoting the usage of integral

abutment and jointless bridges (IAB) and a large number of IABs have been constructed in many states. However, due to Louisiana's unique soil conditions and the complexity of the pile and soil interaction in the integral abutment bridges, no full integral bridge was ever considered in Louisiana until 2011.

Few studies investigated the behavior of IAB support piles (e.g., Jorgenson 1983; Card and Carder 1993; Abendroth et al. 2005; Arsoy 2000; Frosch et al. 2005, Girton et al. 1991; Lawver et al. 2007; Yannotti, et al. 2005). Selecting and installing an appropriate pile is important in the design of integral abutment bridge since the pile must withstand annual thermal displacements. When the piles are embedded into the abutment, the monolithic nature of the structure would cause them to translate and rotate with the superstructure when the temperature changes. The rigid pile-to-abutment connection and fixity at the pile base makes the pile perform as fixed-fixed columns. Square PPC piles are common foundation piles for Louisiana bridges, but the state has concerns about the rigidity of the piles, especially if they are driven in sandy soils. This paper presents the field performance of pile foundation for the first IAB in Louisiana with emphasis on the behavior of the piles and the bent-soil interaction. The behavior of the super-structure will be presented in another paper.

2 Instrumentation Plan for Caminada Bay Bridge Site

The bridge is located at Grand Isle, Louisiana, USA (29°15'48" N 89°57'24" W), about 100 miles (160 km) to the south of New Orleans. The total length of the bridge is 3945 ft (1202 m). The monitoring program was conducted on the first 11 spans. The width of the bridge is 50 ft (15.2 m) consisting of two 21 ft (6.4 m) lanes and a 7 ft (2.1 m sidewalk on the northern side. The slabs are fully integrated with the first bent (Bent 1) at the left end, simply supported on the eleventh bent (Bent 11) at the right end, and rigidly connected with all the interior bents. Each bent is supported by a single row of four PPC piles with a square cross section of 36 in (914 mm, Fig. 1). In addition, the material properties designed for this bridge are summarized as follows: (a) Class AA (M) concrete, with a compressive strength of 4060 psi (28 MPa), was used for the slabs and bents; (b) Class P (M) high performance concrete, with a minimum compressive strength of 6000 psi (41 MPa) at 28 days, and an average compressive strength of 10,000 psi (69 MPa) at 56 days, was used for the PPC piles; (c) Type 316LN stainless steel, with an elastic modulus of 29000 ksi, a tensile strength of 75 ksi, and a yield stress of 30 ksi, was used for the deformed reinforcing steels in the bents and slabs; (d) Grade 60 black steel, with a 60 ksi yield stress, was used for all the other deformed reinforcing steels; (e) Grade 270 steel, with a 270 ksi yield strength, was used for the pre-stressing strands.

Table 1 lists the properties of soils in Borehole 1, which was drilled at Bent 1. The piles are 60 ft (18.3 m) long that were mainly driven into the fine sand deposit. Figure 2 shows the instrumentation plan for the IAB. It included two piles, one abutment, and a backfill on one side of the bridge. Bridge Diagnostics, Inc. (BDI) There are other sensor measurements not reported in this paper due to page limitations and the scope of the paper. BDI installed all the sensors. Before the piles were cast, 32 sisterbar strain gauges (GeoKon model 4911) were attached to pre-stressing steel of two piles (16 gauges in
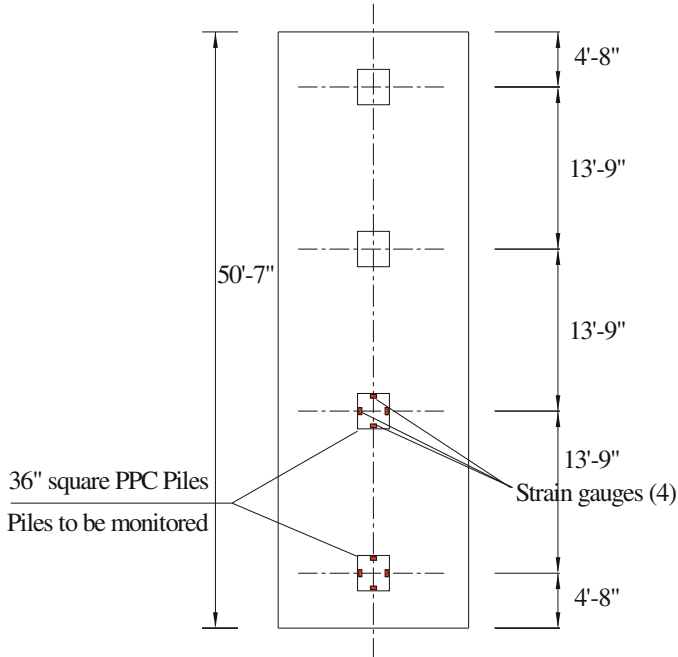
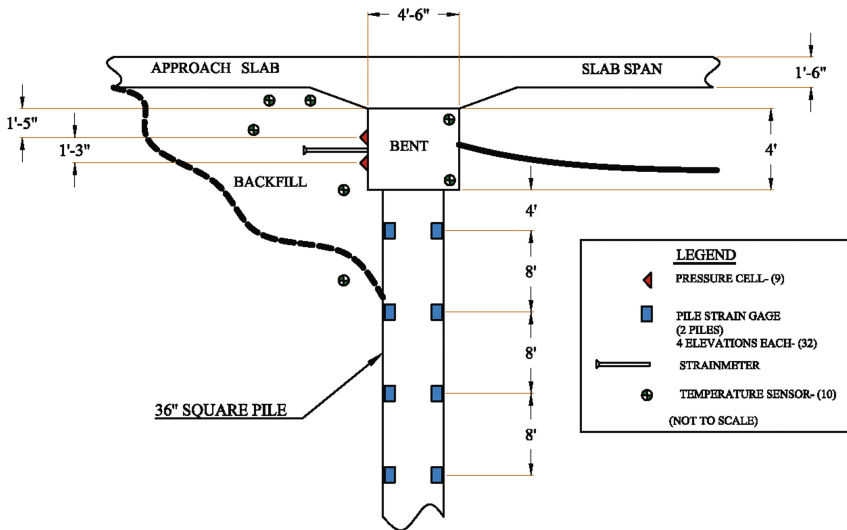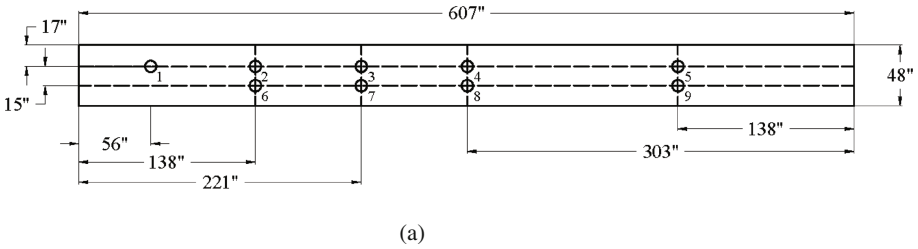**Fig. 1.** Plan view of piles layout and Bent 1 top view dimensions.

Fig. 2. Instrumentation plan for Bent 1 of Caminada Bay bridge-substructure.

Table 1. Soil properties in Borehole 1 drilled at Bent 1.

| Soil Description	Wet Density (lb/ft³)	Moisture Content (%)	Liquid Limit	Plasticity Index	q_u (tsf)	SPT or UU (tsf)	Elevation (ft)
							0
Tan fine sand with traces of silt						N-11	
						N-13	−5
						N-15	−10
Grey fine sand with traces of silt						N-18	
						N-11	−15
						N-13	−20
Grey fine sand						N-6	
						N-9	−25
Grey fine sand with traces of silt						N-21	
							−30
Grey silty fine sand						N-22	
						N-17	−35
						N-13	
Tan and grey fine sand	101	31				0.67 at 17.8 psi	−40
Grey fine sand with traces of silt						N-10	−45
						N-16	
Grey fine sand	112	25				3.44 at 21.3 psi	−50
						N-44	
Grey fine sand with traces of silt						N-42	−55
						N-33	−60
						N-35	
							−65
Grey clay	106	51	86	55	0.92	N-8	
							−70
Grey clay with silt lenses	112	28			0.68		−75
							−80
Grey clay	113	48	51	29	1.35		
	112						−85
Grey slightly silty clay	118	33	42	24	0.7		−90
Grey clay with silt lenses	109	44			1.44		−95
Grey very sandy clay	123	24	31	13	1.10		−100
Grey sandy clay	120	27			1.28		−105
							−110

(a)

(b)

Fig. 3. (a) Schematic of location of pressure cells on the face of bent 1. (b) Photo of pressure cells mounted on Bent 1 face.

each pile) in the concrete cast yard. After applying the pre-stressing tension to the tendons, the concrete was cast, and the piles were shipped to the bridge site. Driving the piles did not damage the sisterbar strain gauges cast inside the piles. Strain gauge integrity was checked before shipping, after arrival, and after pile driving. The pressure cells (GeoKon model 4810) were mounted at the locations shown in Fig. 2 using stainless steel mounting hardware. In addition, BDI provided a mason to place a small pad of mortar behind each cell during installation to ensure that it would make uniform contact with the concrete surface (Fig. 3).

3   Behavior of Piles and Bent-Soil Interaction

The soil pressure measurements were recorded using the nine pressure cells that were mounted on the face of the bent (Fig. 3). Figure 4 shows a summary of the soil pressure measurements. A zoom in of the measurements for few days in January (cold days) and July of 2012 (hot days) are depicted in Figs. 5 and 6, respectively. One can notice that
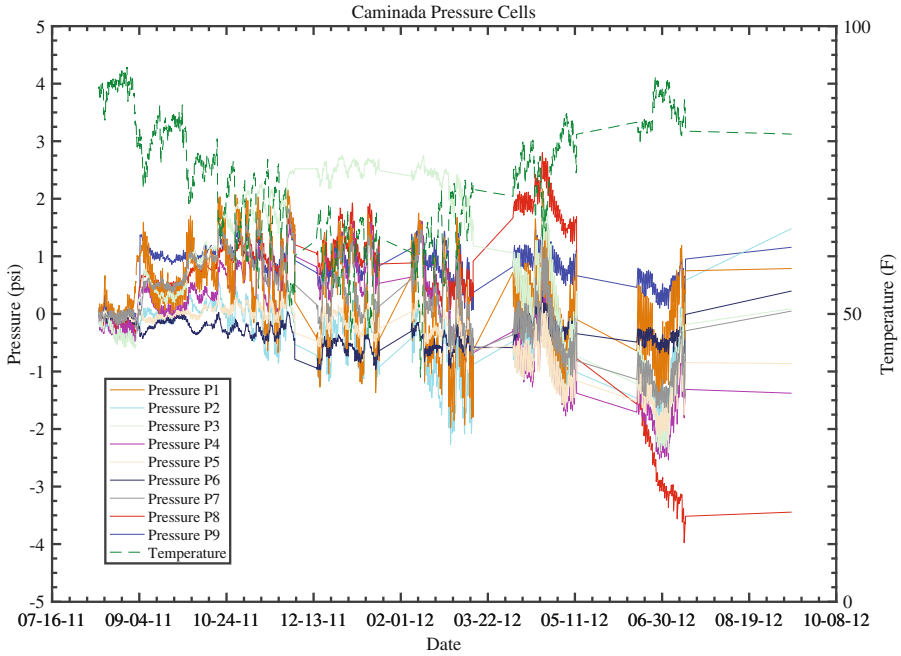
Fig. 4. Pressures from all Caminada pressure cells for entire dataset.

the bridge shrunk in cold weather which caused the soil pressure to drop to zero or a small negative value and expanded in hot weather which results in a maximum of 3 psi (20.7 kPa) passive pressure on soil.

To calculate the bending moments in the piles, the micro-strains for each of the sisterbar strain gauges were normalized based on the reading collected at the time of installation and were corrected for temperature effects. The following are the strains that were used to calculate the moments in the respective direction:

$$\varepsilon_t = (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)/4 \tag{1}$$

$$\varepsilon_x = (\varepsilon_1 + \varepsilon_2 - \varepsilon_3 - \varepsilon_4)/4 \tag{2}$$

$$\varepsilon_y = (-\varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \varepsilon_4)/4 \tag{3}$$

where $\varepsilon_1 - \varepsilon_4$ are the measured strains in the four corners of the pile and $\varepsilon_t, \varepsilon_x$, and ε_y are the strains in the transverse, x, and y directions (Fig. 7), respectively. The moments were calculated as:

$$M = \frac{E \times I \times \varepsilon}{h} \tag{4}$$
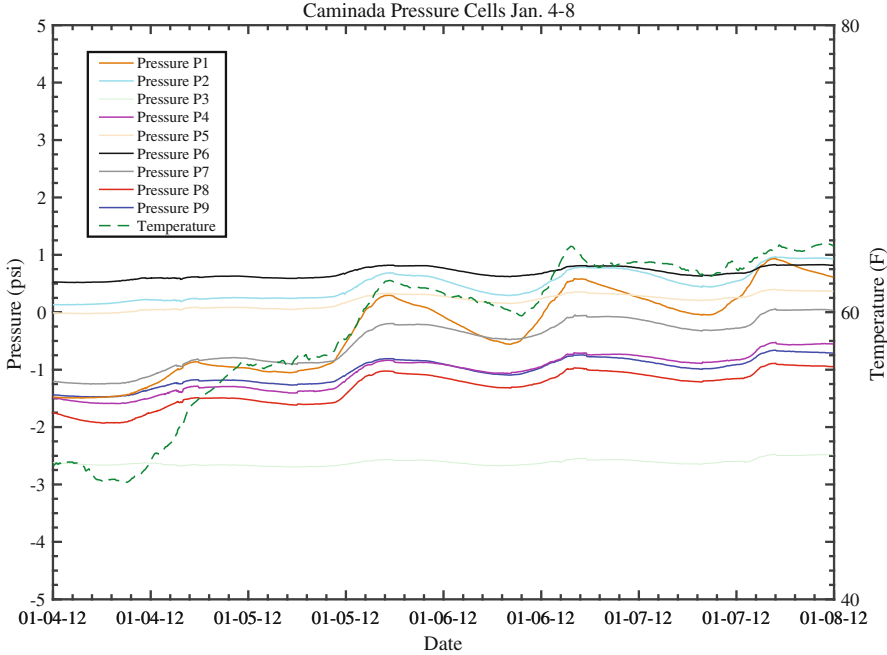
Fig. 5. Pressures from all Caminada pressure cells for Jan. 4, 2012 Jan. 8, 2012.

where M is the directional bending moment, E is the modulus of elasticity, I is the mass moment of inertia, ε is the directional strain, and h is the distance between the sensors. The modulus of elasticity for the piles was computed as:

$$E = 57,000\sqrt{f_c'} \tag{5}$$

where f_c' is the compressive strength of the concrete after 28 days (6000 psi = 41,370 kPa). The mass moment of inertia was calculated based on the gross area of the pile. The moment in each direction was then calculated for each section of the pile based on the strain in the representative direction. Moments were calculated for the interior and exterior piles on October 1, 2011; January 1, 2012; April 6, 2012; and July 7, 2012 using the average strain during a particular day. The cracking moment for the pile was calculated assuming no pre-tension. Since concrete cracks in tension, the modulus of rupture was used to determine when the pile will crack. The modulus of rupture (f_r) is equal to 7.5 times the square root of the concrete compressive strength per ACI code. The cracking moment was calculated using the following equation:

$$M_{cr} = \frac{f_r \times I}{c} \tag{6}$$

where M_{cr} is the cracking moment, c is the distance of the tensile fibers to the neutral axis (half the pile width = 18 in. (457.2 mm)), and I is the mass moment of inertia of
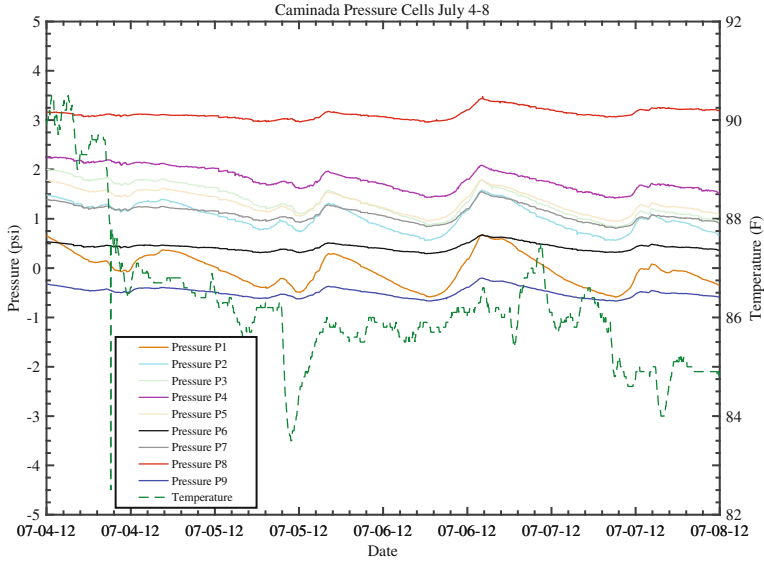
Fig. 6. Pressures from all Caminada pressure cells for July 4, 2012-July 8, 2012.
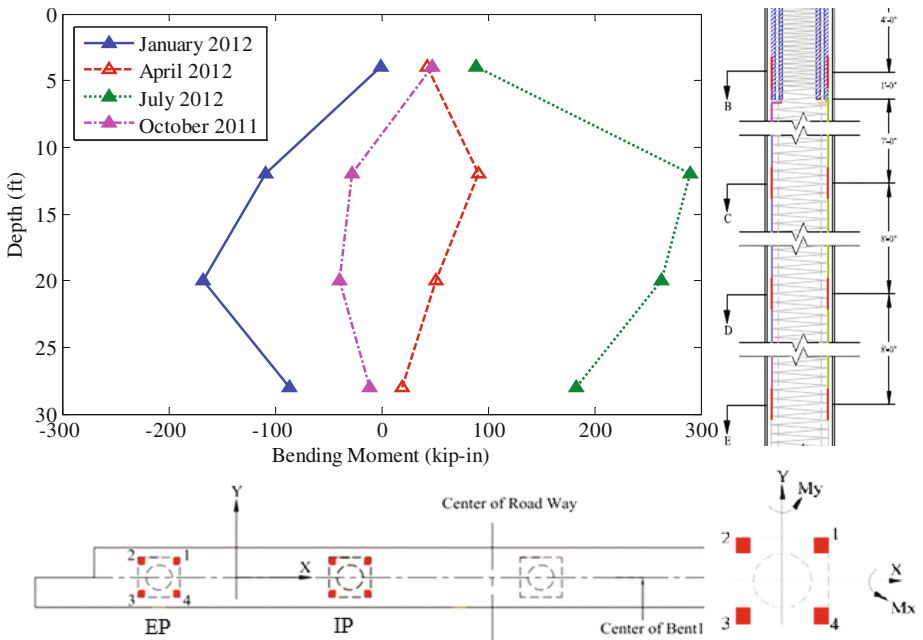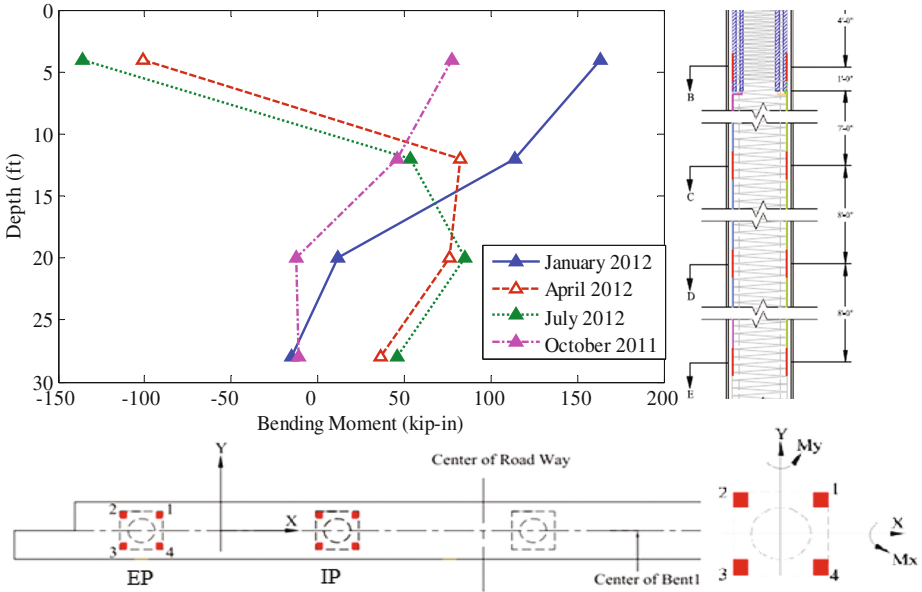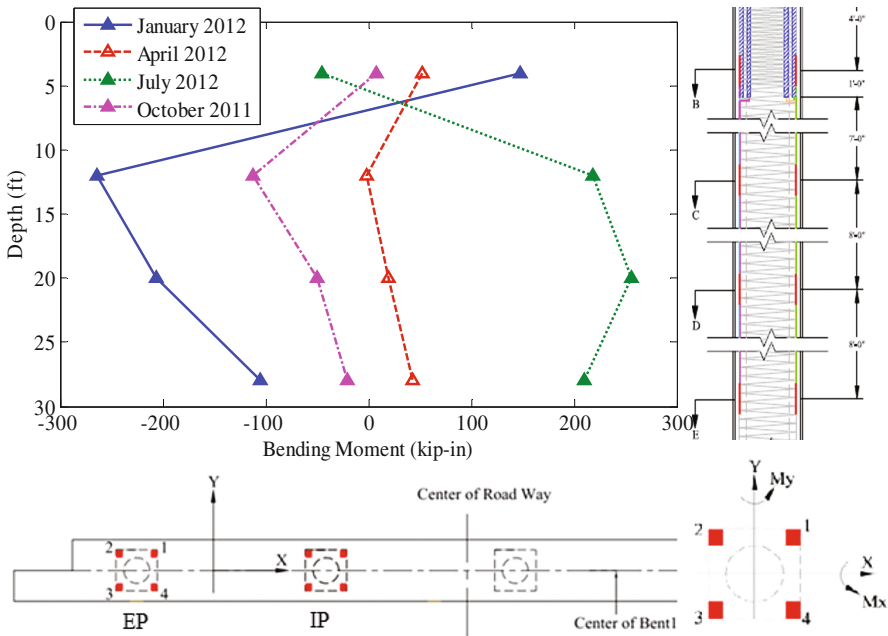

Fig. 7. Moment about x-axis, M_x in the interior pile obtained from strain gauge data. Theoretical cracking moment is 4518 kip-in.
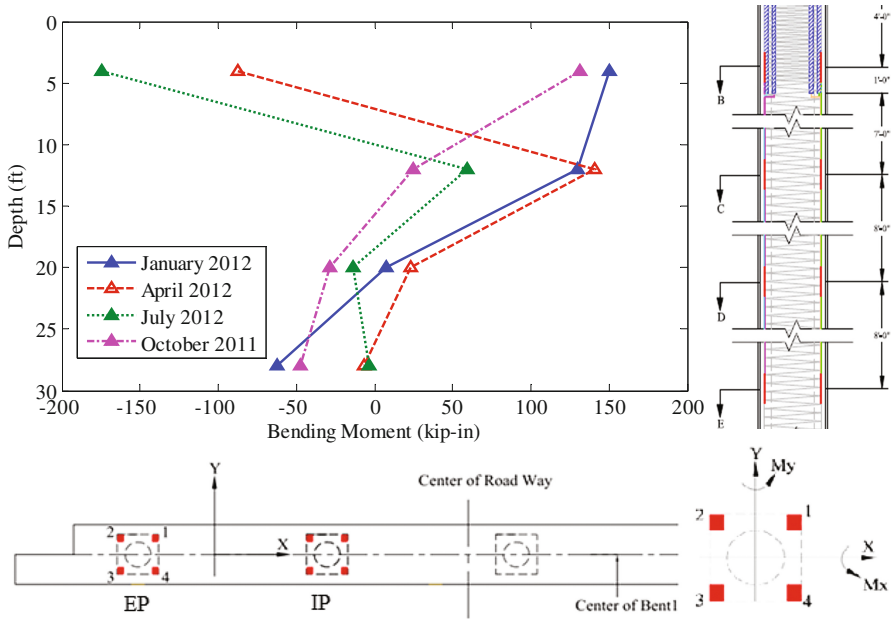
Fig. 8. Moment about y-axis, M_y in interior pile obtained from strain gauge data. Theoretical cracking moment is 4518 kip-in.

Fig. 9. Moment about x-axis, M_x in the exterior pile obtained from strain gauge data. Theoretical cracking moment is 4518 kip-in.

Fig. 10. Moment about y-axis, M_y in exterior pile obtained from strain gauge data. Theoretical cracking moment is 4518 kip-in.

pile cross-section (139,968 in^4 = 5.8 × 10^{10} mm^2). The bending moments in the interior and exterior piles are shown in Figs. 7 through 10. The moments in the direction of traffic (Figs. 7 and 9) show typical trends with values that range from −200 kip-in to 200 kip-in. Systematic change is evident with temperature fluctuations; for example, January and July represent cold and hot sessions, respectively. Moment trends in piles due to bridge deck thermal expansion and contraction resulted in negative moments in January (contraction) and positive moments in July. Moderate temperatures in April and October resulted in smaller moments. Moments in the transverse direction (90° to the direction of traffic, Fig. 10) do not show a clear trend with season but rather similar trends for April through July and January through October with overall moment ranges less than the moments in the direction of traffic. There are fewer thermal expansions in the transverse direction. and south Louisiana is warm with no major temperature changes from April to July and October to January. The concrete cracking of the pile is 4518 kip-in. Clearly, the piles experienced small moments, and the design is very conservative (Fig. 8).

4 Conclusions

The paper presented an instrumentation plan for two piles and the supporting bent of Caminada Bay bridge, the first IAB bridge constructed in Louisiana. The PPC square piles are 60 ft (18.3 m) long and were driven into mainly fine sand deposit. Two piles were instrumented with sisterbar strain gauges along with pressure cells at bent-soil

interaction. The instruments were monitored during the period of August 2011 through September 2012. The bridge expanded and contracted with temperature changes. The bridge deformations were mainly controlled by the piles' rigidity, soil resistances surrounding the piles, and connection behaviors between the pile-bent. Based on the observed temperature effects, the design of the piles of Caminada Bay Bridge were very conservative. The piles experienced very low bending moments, and the bent imposed very small amount of pressure on the backfill soil.

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