Instrumentation Plan for Monitoring the New I-10 Twin Span Bridge

Murad Y. Abu-Farsakh[1], Ph.D., P.E. (Corresponding Author)
Research Associate Professor
e-mail cefars@lsu.edu

Sungmin Yoon[2], Ph.D., P.E.

Da Ha[3], Ph.D.

W. Allen Marr[3], Ph.D.

Zhongjie Zhang[4], Ph.D., P.E.

Ching Tsai[2], Ph.D., P.E.

Zhengzheng Fu[2], P.E.

and

Arthur D'Andrea[2], P.E.

[1] Louisiana Transportation Research Center (LTRC), Louisiana State University, Baton Rouge, LA.
[2] Louisiana Department of Transportation and Development, Baton Rouge, LA.
[3] Geocomp Corporation, Boxborough, MA.
[4] Louisiana Transportation Research Center (LTRC), Baton Rouge, LA.

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ABSTRACT

The new I-10 Twin Span Bridge over Lake Pontchartrain is being constructed to replace the existing bridge, which was damaged by Hurricane Katrina in 2005. The new bridge was designed to be higher and stronger than the existing bridge. The new bridge will be supported by groups of battered pile foundations. The Louisiana Department of Transportation and Development (LADOTD) decided to install a substructure and superstructure health monitoring system on a selected bridge pier (M19 eastbound) at the main span for short-term and long-term monitoring of the bridge. The substructure instrumentation for the M19 eastbound pier includes strain gauges and In-Place Inclinometers (IPI) installed inside the piles, and triaxial accelerometers, water pressure cells, tiltmeters, and corrosion meters installed on the pile cap. A lateral load test was designed and conducted to evaluate the validity of the analysis method used to design the battered pile foundations. Horizontal movements of the pier caps and bents were monitored using an automated survey station with prisms. This paper will discuss the substructure instrumentation plan and the novel approaches to preparation and the design of lateral load testing of battered pile-group foundation.

KEY WORDS: Substructure Monitoring System, Lateral Load Test, Pile Foundation, Pile Instrumentation, FB-MultiPier, Smart Bridge.

INTRODUCTION

The importance of developing structural health monitoring (SHM) systems to evaluate the performance of civil engineering structures has been realized at national and state levels since the 1990s. This interest was motivated mainly by the need to diagnose the status of aging structures that continue to deteriorate and to optimize the cost of bridge maintenance. Since then, several research projects were funded by the National Science Foundation (NSF), Federal Highway Administration (FHWA), and state Departments of Transportation (DOTs) (1, 2). However, the necessity for structural health monitoring of bridges (both superstructure and substructure) has gained a great momentum since the tragic collapse of I-35 St. Anthony Falls Bridge over Mississippi River in Minneapolis, Minnesota in August, 2007.

Several new-build bridges were recently instrumented with various types of sensors for structural health monitoring (3, 4, 5). The new Svinesund Bridge joining Sweden and Norway across the Ide Fjord was instrumented with various types of sensors installed at different locations of the arch to monitor the bridge during the construction phase and during the first five years of its service life (5). A substructure health monitoring (SSHM) program was implemented at the new I-35 bridge in Minneapolis, Minnesota that was built to replace the collapsed bridge to provide live monitoring of substructure loads during construction and ultimately long-term health monitoring of the bridge (4). The Florida Department of Transportation arranged for three barge impacts on a selected bridge pier at St. George Island Causeway to be demolished in order to conduct a full-scale barge-bridge impact test (5). The bridge was instrumented with soil total stress and pore pressure gauges in front and behind the pile cap, fully instrumented pile with strain gauges along its length, dynamic load cells to monitor the barge impact loads, and accelerometers to monitor pier acceleration, velocities, and displacements.

This paper will focus on the design and development of the substructure instrumentation plan on the M19 eastbound pier of the new I-10 Twin Span Bridge over Lake Pontchartrain and the subsequent lateral load test that was conducted to validate the analysis method used to design the battered pile-group foundations.

DESCRIPTION OF M19 PIER

The new I-10 Twin Span Bridge includes the construction of a 5.4-mile long bridge located 300 ft. east of the current bridge. The new bridge will have an elevation of 30 ft., which is 21 ft. higher than the old bridge, and an 80-ft. high-rise section near the Slidell side to allow for marine traffic making it less susceptible to high storm surge.

LADOTD selected the M19 eastbound pier at the main span of the bridge to install a structural health monitoring system, which includes both substructure and superstructure instrumentations for use in short-term and long-term monitoring of the bridge. The M19 pier supports 200-ft. long steel girders in the north side and 135-ft. long concrete girders in the south side. The bridge foundations consist of square precast prestressed concrete (PPC) piles. The foundations of M19 eastbound and westbound piers consist of 24 PPC 110-ft. long battered piles (batter slope 1:6) with an outer dimension of 36 in. and a circular void of 22.5 in. The average pile embedded length was 87 ft. The size of pile cap (or footing) of the M19 piers is 44 ft. × 42.5 ft. × 7 ft. The water depth is 11 ft. Figure 1 presents the M19 eastbound and westbound piers site.

Figure 1. Photo of M19 Eastbound and Westbound Piers Site

SUBSURFACE CONDITION AT M19 PIER SITE

One soil boring was performed close to the M19 pier down to 200 ft. A total of 48 Shelby tube samples were extracted from cohesive layers for laboratory testing. Standard penetration tests (SPT) were also conducted in sandy layers. The laboratory testing program included moisture content, soil unit weight, Atterberg limits, and unconsolidated undrained (UU) triaxial tests.

The in-situ testing at the M19 pier included performing five cone penetration tests (CPTs) down to 160 ft. each, one CPT at the mid of the M19 pier, and four CPTs at 5-10 ft distances. out from the four corners of the pile cap.

The laboratory and in-situ tests at the M19 pier site revealed the subsurface soil condition for the M19 site as follows: from 0 ft. to 35 ft. medium to stiff gray and tan silty clay to clay soil with silt and sand pockets and seams with undrained shear strength ranging from 0.28 tsf to 1.43 tsf; from 35 ft. to 47 ft. medium to dense light gray sand and clayey sand with SPT-N values ranging from 16 to 22; from 47 ft. to 110 ft. medium to stiff gray clay and silty clay with sandy clay/silt pockets with undrained shear strength ranges between 0.76 tsf and 2.02 tsf; and 110 ft. to 200 ft. medium dense to very dense sand with interlayers of silty sand, clayey sand, and silty clay soil with SPT-N values range from 3 for loose clayey sand to 86 for the very dense sand.

SUBSTRUCTURE INSTRUMENTATION MONITORING PLAN

In order to address some concerns that arose during the design of the new I-10 Twin Span Bridge, LADOTD engineers decided to install a structure health monitoring system on the M19 eastbound pier. The system, which includes instrumenting both the substructure and superstructure of the pier, will be used for short-term and long-term monitoring of the bridge.

The substructure monitoring system includes instrumenting eight selected piles with inclinometers and strain gauges and instrumenting the pile-cap with accelerometers, tiltmeters, water pressure cells, and corrosion meters as described next. A plan view of M19 footing with the layout of substructure instrumentation is presented in Figure 2. The superstructure monitoring system includes instrumenting columns, bent cap, three steel girders, three concrete girders, and one diaphragm with strain gauges and corrosion meters. A Weigh In Motion (WIM) system will be installed at the concrete bridge deck of the M19 eastbound pier. This paper focuses on the discussion of the substructure instrumentation plan of M19 eastbound pier and the subsequent lateral load test that was conducted on the pier.

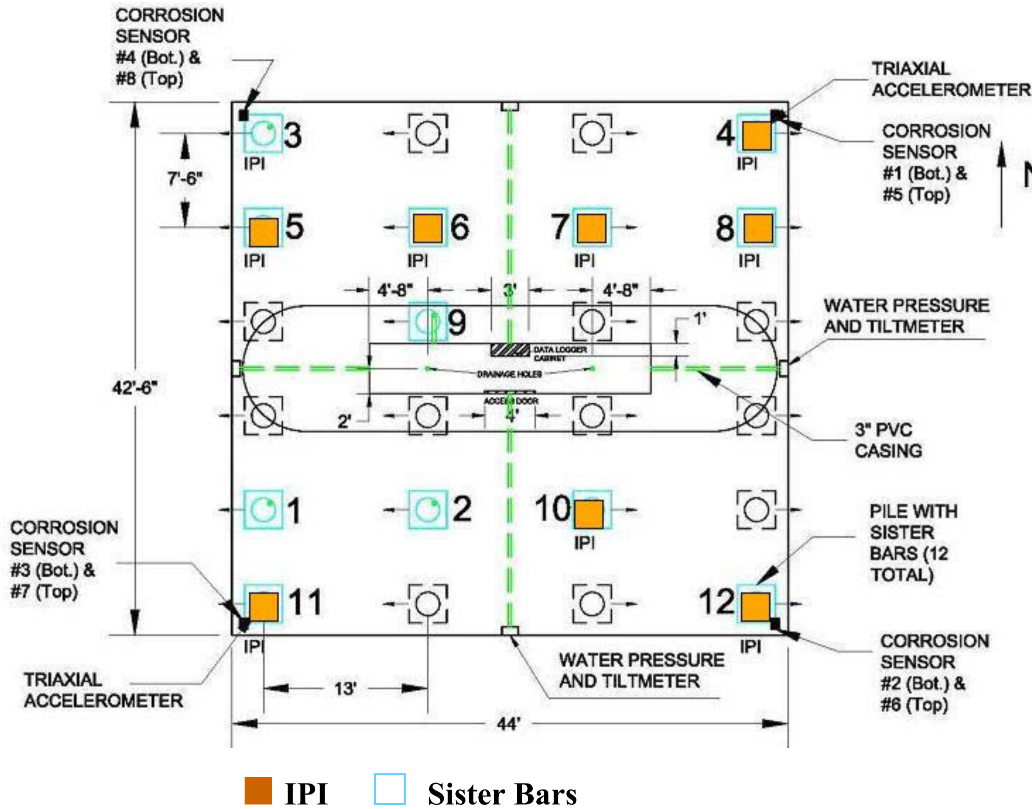
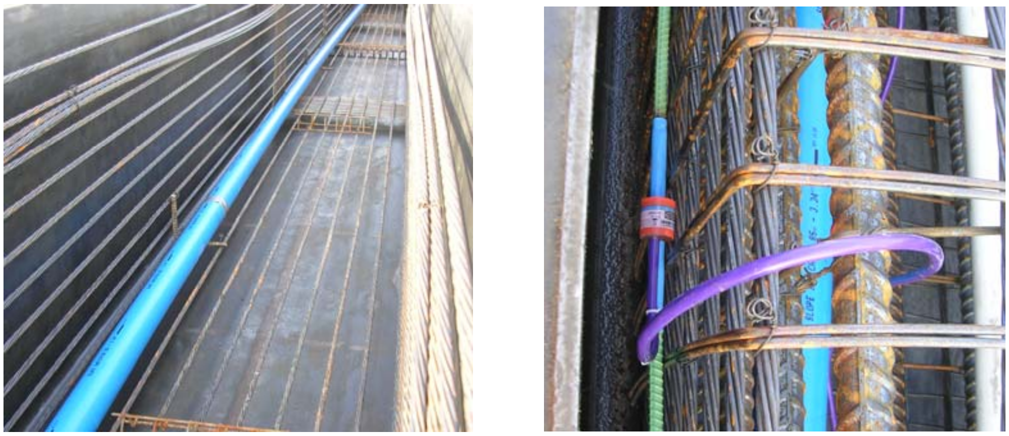


Figure 2. Plan View of M19 Pier Footing with Layout of Substructure Instrumentation

Instrumentation Plan of Piles

Eight selected piles (numbers 4, 5, 6, 7, 8, 10, 11, and 12) were instrumented with In-Place Inclinometers (IPI) Micro Electro Mechanical Sensor (MEMS) sensors. IPI consists of a string "node" of tilt sensors connected together and placed in the pile foundation through a PVC casing. It can measure the position change (inclination) in each node in a direction perpendicular to the axis of the string. Each pile was instrumented with six inclinometer sensors located at elevations of -65, -45, -35, -25, -15, and -5 ft. from the bottom level of the pile cap.

Twelve selected piles (numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12) were instrumented with resistance type sister bar strain gauges to measure the strain distribution at the locations close to the pile cap caused by the applied lateral load. Each pile was instrumented with two pairs of strain gauges at -16 ft. and -21 ft. from the top of the pile in the casting yard. Figure 3 presents photos of pile instrumentations during pile casting. The piles' strain changes were monitored during casting, strand cutting, and storage. Pile 1 was also instrumented with data logger to monitor the strain change during delivery (Figure 4). It can be seen that the pile experienced appreciable strain change only when the pile was moved for storage (August) and when the pile was moved to barge for delivery (end of October).



(a) Installed IPI Casing (b) Installed Strain Gauge

Figure 3. Pile Instrumentation

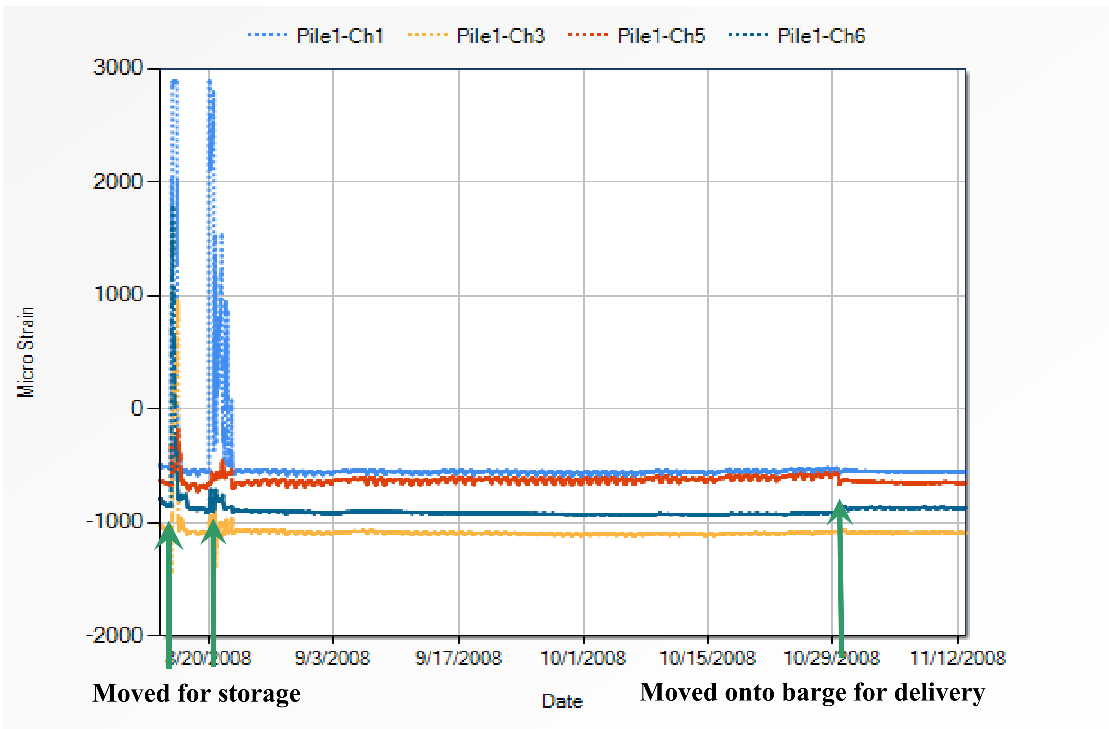


Figure 4. Recorded Strain Change for Pile 1 during Storage and Delivery

Instrumentation Plan of Pile Cap

Two triaxial accelerometers were installed on top of the pile cap at two corners across from each other [northeastern (NE) and southwestern (SW) corners]. Accelerometers will be used to measure any applied dynamic load during the long-term monitoring of the M19 pier and to setup a trigger criterion system to start collecting and saving data from other instrumentations in any event for future analysis. Four uniaxial MEMS tiltmeters were installed at the mid-width of pile cap's four sides to measure the rotation of the pile cap. Tiltmeters will be used to measure any tilt in the pile cap during long-term monitoring. Eight water pressure transducers were installed mount flush with the pile cap facings (two per facing) to measure the water wave force impact during selected events. In addition, eight corrosion meters were installed in the pile cap, and two corrosion meters at each corner at top and bottom of the pile cap to measure any corrosion that might occur during the long-term monitoring.

LATERAL LOAD TEST

A unique lateral load test was designed and conducted at M19 piers of the new I-10 Twin Span Bridge to evaluate the analysis method used to design the bridge pile foundations and for long-term monitoring of the bridge. The test was conducted by pulling the M19 eastbound and westbound piers toward each other using high strength steel tendons that were run through the pile caps via pre-installed 4-in. diameter PVC pipes. Each steel tendon includes 19 0.62-in. diameter strands of low relaxation, high yield strength steel (Es = 28,500 ksi). Six MEMS IPI inclinometer sensors were calibrated and properly installed in each of the eight selected piles at specified depths of 5, 15, 25, 35, 45, and 65 ft. from the bottom level of the pile cap with the lowest one tied to an anchor point at 85 ft. from the bottom of the pile cap.

The substructure monitoring system was temporarily assembled two days before the test to allow the collection of data from all instruments during the lateral load test. This includes connecting the IPI sensors and strain gauges to data loggers that were housed inside the eastbound pier protection wall. Data loggers were then connected via internet phone to the data acquisition server at Geocomp Headquarters in Boxborough, MA. The initial readings of all instrumentations before the load test were recorded. Survey station prisms were installed at M19 eastbound and westbound, M17 eastbound, and M20 eastbound to monitor the movements of footings and bent caps of the M19 piers using an automated laser survey system. Figure 1 presents a photo of the load test site at M19 eastbound and westbound piers.

The setup of the lateral load test started two days before the test. Two floating barges were deployed to the site. One barge was placed between the two pile caps to allow access and to provide support to steel strand tendons to eliminate slack and keep them out of water. Another barge was placed next to M19 westbound to carry jacking/hydraulic equipment setup and to allow access to the live-end side. The steel strands were run through 4-in. PVC pipes one by one from the dead-end at M19 eastbound toward the live-end at M19 westbound. Steel strands were first anchored at the dead-end side. A 600-ton jack was installed for each steel tendon at the live-end. The strands were anchored at the live-end, and then each strand was pre-loaded to 2 kips using two 10-ton monostrand jacks. Figure 5 presents photos for the setup of the lateral load test.

The designed loading and unloading sequence of the lateral load test includes pre-loading each tendon to 300 kips, increasing the load incrementally to 600 kips, unloading to 300 kips, reloading to 1000 kips, unloading again to 300 kips, and finally cutting the strands. The duration time per load increment ranged from 5 min. to 30 min. The horizontal movements of footings and bent caps of the two M19 piers were monitored using an automated laser survey system. This was in addition to live monitoring the strains and IPI deformation measurements, within the foundation piles after each load increment. LADOTD bridge engineers setup two different criteria to start unloading the test at any time before reaching the intended max-applied load of 2000 kips: (1) if the maximum lateral displacement of the M19 westbound bent cap reaches 3/4 in. or (2) if the maximum change in tension strain at the top two strain gauges in pile 8 reaches 160 microstrains, which corresponds to a maximum negative moment of 750 kip-ft. These criteria did not occurr during the lateral load test; however, the test was unloaded earlier at a maximum applied load of 1870 kips when the stroke in one 600-ton jack reached its maximum.

The profiles of lateral deformations for piles 4 and 10 measured using IPI inclinometers at different applied loads are presented in Figure 6a and b. The figure indicates that most of the lateral deformation occurred within the upper 50 ft. of the piles' length. The maximum lateral deformation measure at 5 ft. from the bottom level of the pile cap ranged from 0.60 in. to 0.72 in. This is in agreement with the measured lateral deformations of the pile cap using the automated laser survey, which are 0.66 in. and 0.58 in. for northwest and southwest corners of the M19 eastbound pier, respectively. The success rate of strain gauges and IPI instrumentations were about 70 percent.

(a) Jacking System at the Live-End of Westbound Pier **(b) Eastbound Pier with Steel Strand Tendons**

Figure 5. Setup of Lateral Load Test

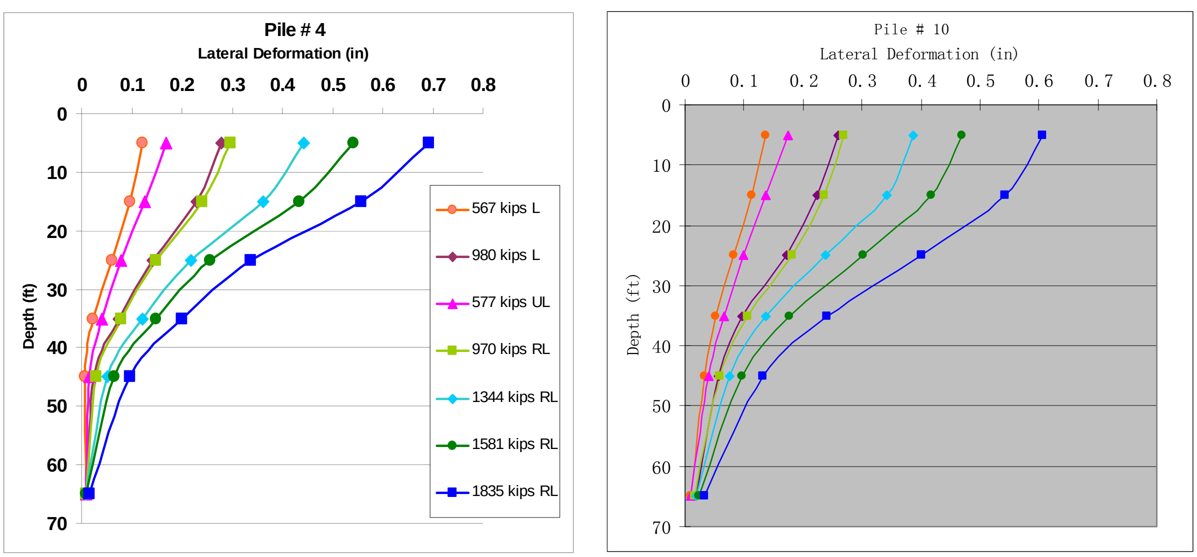


Figure 6. Profiles of Lateral Deformation for Piles 4 and 10 with Load Increments

CONCLUSIONS

This paper presented the design and development of a substructural health monitoring system at the M19 eastbound pier of the new I-10 Twin Span Bidge for use in the short-term and long-term monitoring of the bridge. The system includes instrumenting selected piles with inclinometers and strain gauges and instrumenting the pile cap with accelerometers, and tiltmeters, water pressure cells, and corrosion meters. A unique lateral load test was designed and conducted at the M19 eastbound pier to assess the validity of the analysis method used to design the battered pile-group foundations.

The substructure instrumentaion system was successfully installed and used to monitor the M19 eastbound pier during the lateral load test. The preparation and design of the lateral load testing were discussed. The test was conducted by pulling the M19 eastbound and westbound piers toward each other using high strength steel tendons using two 600-ton jacks. The horizontal movements of the pier caps and bents were monitored using an automated survey. A maximum lateral load of 1870 kips was applied in increments, and the corresponding maximum lateral deformation of the M19 eastbound pier cap as measured using the laser survey was 0.66 in. at the northwest corner and 0.58 in. at the southwest corner. The maximum lateral deformation of piles measured at 5 ft. from the bottom level of the pile cap using IPI sensors ranged from 0.65 in. to 0.72 in.

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