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Structural Health Monitoring of I-10 Twin Span Bridge

INTRODUCTION

A new I-10 Twin Span Bridge was built over Lake Pontchartrain between New Orleans and Slidell, Louisiana to replace the old bridge that was seriously damaged from the storm surge associated with Hurricane Katrina (Category 3) that hit the southern part of Louisiana in August 2005. It was designed with higher capability to withstand extreme events such as hurricane storm surges and ship impacts. The new bridge is around 5.4-miles long located 300 ft. to the east of the old bridge with an elevation of 30 ft., 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. The bridge consists of two parallel structures with three 12-ft. travel lanes and two 12-ft. shoulders on each side (60 ft. wide), allowing for a 50 percent increase in the traffic volume. Some piers of the new bridge are supported by precast pre-stressed concrete (PPC) batter pile group foundations.

To evaluate the current design methodology of batter pile group foundations and to monitor the long-term performance of the bridge, DOTD decided to install a structural health monitoring (SHM) system on a selected bridge pier (M19 eastbound) for short-term monitoring during the lateral load test and long-term monitoring of the structural health of the bridge during selected events such winds, waves, and vessel collision. The foundations of the M19 eastbound pier consists of 24 PPC, 110 ft. long, and 36 in. wide batter piles (slope 1:6). The SHM system includes instrumenting both the substructure and the superstructure. The substructure system includes instrumenting selected piles with In-Place Inclinometers (IPIs) and strain gauges, instrumenting the pile cap with acceleration, tiltmeters, water pressure cells, and corrosion meters. The superstructure system includes instrumenting the columns, bent cap, three steel girders, three concrete girders, and one diaphragm with strain gauges and corrosion meters. Additionally, an Osmos type weight-in-motion (WIM) system was installed to determine the truck loading.

The short-term focus of the SHM was on monitoring the bridge substructure during the lateral load test. A large-scale lateral load test was designed and performed on a well-instrumented pier-cap-pile system (M19 eastbound pier) to study the lateral behavior of the bridge under lateral loads. Another task of the lateral load test was to verify the FB-MultiPier software currently used by DOTD for designing batter pile group foundations. Findings from these lateral load tests will be used for design of batter pile group foundations in similar condition.

OBJECTIVE

The objective of this research project was to establish a bridge structural health monitoring system for use in short-term and long-term monitoring purposes. The short-term monitoring: to evaluate the lateral behavior of batter pile group, to validate the analysis method used to design the pile-group foundations (i.e., FB-MultiPier software), and to back-calculate the p-y multipliers for battered pile groups in similar soil conditions by conducting a lateral load test. The long-term monitoring: to evaluate the behavior of pile group structure under dynamic loads caused by selected events (wind, waves, and vessel collision).

SCOPE

This study implemented a bridge health monitoring system for the new I-10 Twin Span Bridge including both substructure and superstructure. The SHM system serves two purposes: short-term monitoring the bridge foundation during lateral load test, and long-term monitoring the bridge during extreme events such as hurricane and ship impacts. The instrumented sensors for the SHM include in-place inclinometer (IPI) and strain gauges to measure piles' deformation, stresses and moments, triaixal accelerometers and tiltmeters to measurer pile cap motion, water pressure cells to measure water pressure of storm surges, strain gauges at bridge girders to measure stresses and moments, and corrosion meters to measure steel corrosion. A lateral load test was conducted on the M19 eastbound pier. The lateral response of the batter pile group was recorded by the

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SHM system. Data interpretation includes analyses of IPI and strain gauge measurements. A high-order-polynomial curve fitting method was adopted to back-calculate the batter pile group response from the measured IPI data and to derive p-y curves. FB-MultiPier program was used to simulate the lateral load test of the batter pile group. The simulation results were compared with measured data as well as the results from the back-calculation.

METHODOLOGY

A SHM system that includes instrumenting both the substructure and superstructure of the M19 eastbound pier was installed on the bridge for short-term monitoring during the lateral load test and long-term monitoring for the structural health of the bridge. A unique lateral load test was designed and conducted at the M19 piers to evaluate the lateral performance of batter pile group foundation and to assess the method used to design the bridge pile foundations (using FB-MultiPier software). The substructure monitoring system was temporally assembled prior to the lateral load test. The initial readings of all instrumentations were recorded before the test. 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. The test was then 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 tendons. A maximum lateral load of 1870 kips was applied in increments. During the lateral load test, all measurements from IPI sensors and strain gauges inside the piles were recorded, in addition to monitoring the horizontal movements of footings and bent caps of the two M19 piers using an automated laser survey system. The strain gauge measurements were used to calculate the bending moments and axial loads of the instrumented piles at two depth locations.

A high-order polynomial curve fitting method was applied for each load increment to fit the measured rotation profiles from the IPI sensors using reduced chi-square minimization of residual error. The fitted rotation curves were then used to deduce the bending moment, shear force, and soil reaction profiles based on the beam on elastic foundation theory. The FB-MultiPier software was also used to analyze the lateral response of the M19 pier under lateral loading for both soil boring and CPT data and using three different pile-cap models. Results of FB-MultiPier analysis were compared with the measured deflection values as well as values calculated from the polynomial curve fitting. The moments deduced from the high-order polynomial curve fitting were compared with the moments calculated from strain gauge measurements and the FB-MultiPier predicted moments. The soils' p-y curves at different depths were back-calculated from the derived soil reaction profiles (p) and the pile lateral deflection profiles (y).

CONCLUSIONS

The maximum lateral deformation of piles measured at 5 ft. below the bottom of the pile cap using IPI sensors ranged from 0.65 in. to 0.72 in., less than expected. The measured lateral deformation profiles showed that the piles' horizontal movements occur within the upper 50-60 ft. below the pile cap and that the shape of lateral deflection profile for different row piles is similar. This suggests that the pile group effects in the loading direction are somehow minimal.

The strain gauge measurements showed that the pile axial loads due to lateral loading are in compression or tension, depending on the pile batter direction. This shows that the batter pile system can improve the horizontal resistance of the pile group by transferring a portion of the applied lateral load into pile axial loads. The results showed that piles in inner rows 2 and 3 carry higher axial loads compared to piles in the other two rows.

The moments deduced from the curve fitting of IPI measurements and the FB-MultiPier are in agreement with the strain gauge measured moments at two different locations. The FB-MultiPier predicted moment profiles have larger negative moments and the depth corresponding to the peak negative moment is shallower compared with the back-calculated IPI moment profiles using high order polynomial curve fitting.

The comparison of p-y curves for piles in different rows indicate slight pile group effects for the leading row piles, with the outer piles in the same row have slight pile group effects (i.e., p-multiplier ≈ 1).

The FB-MultiPier analysis based on the modified models and considering the installation effect showed much better predictions of the measured lateral deformations, and the shape of the deflection profiles is similar to the measurement values.

RECOMMENDATIONS

It is recommended that DOTD bridge design engineers consider using less conservative p-multipliers when using the FB-MultiPier software for analysis and design of batter pile group foundations loaded laterally along the batter direction.

It is recommended that DOTD bridge design engineers consider using the modified FB-MultiPier meshes as presented in Figures 84b and 84c of the original report for improving analysis and design of pile group foundations.

The DOTD engineers need to be aware of the effect of pile installation and the subsequent soil densification, consolidation and set-up on the increase of strength properties of surrounding soils.

For future instrumentations of bridge foundations, the researchers recommend instrumenting selected piles with a series of strain gauges along the depth (in addition to inclinometers) in order to be able to measure the moment distribution along the pile during testing and monitoring.

It is recommended that a future research project use a continuum-based non-linear finite element numerical modeling using ABAQUS software to study the lateral behavior of the batter pile group foundation and their interaction with the surrounding geomaterials under both static and impact type of lateral loads.