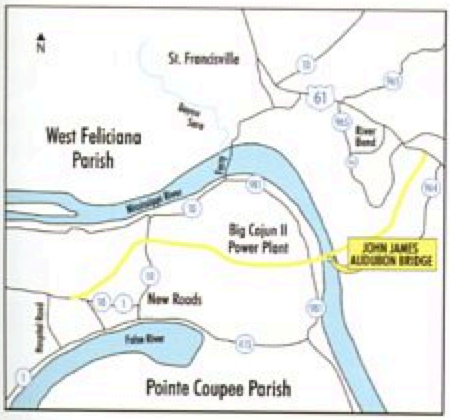
Deep Foundations for a Record-Setting Cable-Stayed Bridge

As the spring flooding of 2011 threatened lives and property on the lower Mississippi, workers rushed to complete the final touches on the Audubon Bridge. The bridge opened several months ahead of schedule in May of 2011. The new bridge is the only one crossing the Mississippi River on the 100+ mi (161 km) section between Baton Rouge and Natchez, Miss., and its opening marked the permanent retirement of the dangerous ferry connecting St. Francisville and New Roads, La. With a 1,583 ft (483 m) main span, this newest Mississippi River crossing surpasses the Cooper River Bridge in Charleston, S.C., as the longest cable-stayed bridge in the western hemisphere. The challenges to meet the deadline for the record-setting project were formidable. Among them were the vagaries of the river and difficulties of construction in the annual high-water conditions and nearby swamps, and the notoriously difficult Louisiana geologic conditions.



Location of the bridge

Besides the new four-lane river crossing, the John James Audubon Bridge project includes 12 mi (20 km) of roadway with 8 smaller bridges plus the high-level approach structures to the river bridge. The project is also the first ever design-build project for the Louisiana Department of Transportation and Development (La DOTD). The $400 million project was awarded in 2006 to Audubon Bridge Constructors, a joint venture of Flatiron Constructors, Granite Construction and Parsons Transportation Group. Dan Brown and Associates designed the foundations for the river bridge and high-level approaches, with PSI performing the geotechnical investigation and the design of the roadway and other bridges.

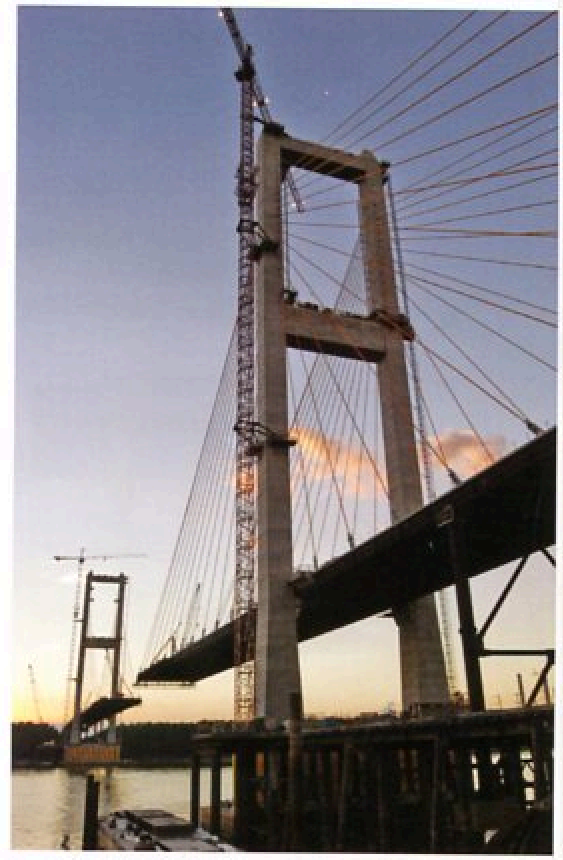
John James Audubon was a world renowned artist who dedicated his life to painting the birds of North America. He painted 32 of his famous works while residing at Oakley Plantation in nearby St. Francisville, and the bridge is named in his honor to highlight the importance of preserving the abundant wildlife and heritage of this region. Besides the beautiful birds Audubon painted, the construction crews had opportunities to observe abundant wildlife on a daily basis — including snakes, alligators and mosquitoes!

The design-build team located the main pylon foundations for the bridge as close to the bank of the river and as far away from the navigation channel as possible. The river width between the levees on either side of the foundation was nearly 3,300 ft (1,000 m), making work in the flood plain and on the pylons during high-water inevitable to meet the schedule. Water levels on the river at this location fluctuate between +5 ft and +56 ft (+2 m to +17 m). Scour at the pylon locations is on the order of elevation -40 ft (+12 m).

Site Geology

During the most recent ice age in Pleistocene times, the Gulf of Mexico was about 400 ft (120 m) lower. The Mississippi River system cut into the flood plain deposits, which were left high and dry, and became overconsolidated by desiccation. Subsequent sea level rise and infilling has created today's Atchafalaya Basin, which is filled with Holocene-age alluvial deposits. At this location, the Mississippi moves toward the east, and thus the overconsolidated Pleistocene deposits are present at shallow depths on the east side of the river and deep soft alluvial deposits on the west.

At the bridge location, the alluvium consists of loose to dense silts and sands in



Looking west from east bank at sunset
(photo credit: Chris Usery, Figg Engineers)

the alluvial deposits, underlain by the Pleistocene-age clays of the Prairie Formation below about elevation -200 ft (-60 m). Within the flood plain to the west, and nearby the river on the east, the shallow soils consist of silts and clays that can be relatively soft. The Pleistocene clays are stiff to very stiff, with undrained shear strengths generally less than 3 ksf to 4 ksf (140 kPa to 190 kPa).

Foundations at the Pylon Towers

The two pylons consist of a 3 by 7 group of 8 ft (2.4 m) diameter drilled shaft foundations, each of which includes base

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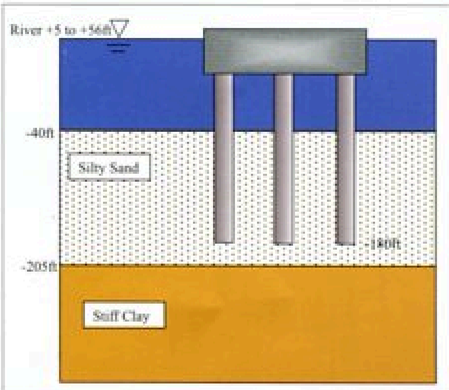
grouting to enhance the axial resistance at the shaft toe. Although other bridges on the lower Mississippi have been constructed using large gravity caisson foundations, the drilled shaft foundations offered a more economical solution with a smaller footprint and a greater embedment that reduces susceptibility to scour. The foundations could also be built faster and with less risk of delays due to river conditions. The project team also considered driven piles, but this approach would have required a much larger and more expensive foundation due to the poor bearing conditions and deep scour.



Ground conditions at the pylon foundation locations

The 8 ft (2.4 m) diameter drilled shafts provided the flexural strength needed to resist lateral loads (including wind and vessel collision) and the deep scour that extended as deep as elevation -60 ft (-18 m) at the pylon locations. The permanent casing, necessary for construction in the river, was incorporated into the design of the drilled shafts for increased flexural stiffness and also to provide confinement.

The drilled shafts were founded at elevation -175 ft to -180 ft (-53 m to -55 m) on the dense sands above the deeper clay, and base grouting helped to increase the base resistance. The available base resistance in the clay was much lower and the clay soils not suitable for improvement by grouting, so that drilled shafts extending into the clay would be at least 80 ft (24 m) longer to provide axial resistance equal to that of the base grouted shafts as designed.

The contractor used an oscillator to install full length segmental casing to stabilize the hole for the drilled shafts. Excavating the sandy soils within the casing was generally done using an airlift system and occasionally using a grab when cohesive layers were encountered. The depths of these shafts in the cohesionless sandy soils pushed the limits of the capabilities of the oscillator equipment. To maintain stability of the ground, and avoid loosening the soils around the drilled shaft excavation, a soil plug was maintained within the casing during excavation, along with a water head in excess of the groundwater levels. The contractor kept the height of the soil plug higher during excavation through the looser shallow soils, then reduced the height of the plug as the excavation approached the design tip elevation to reduce the torque requirements on the oscillator. The drilled shaft was completed with the casing extending approximately 2 ft (0.6 m) below the base of the excavation.

These limits of the oscillator technology were determined in the usual way, by stepping over the limits and then adjusting. On two occasions during the project, the casing became stuck and was left in place. When workers completed each of these foundations and base grouted successfully, we employed Osterberg cells (O-cells) within the production shafts to provide proof testing of the axial capacity of the completed shaft.

After concrete placement for a drilled shaft and the crosshole sonic logging (CSL) integrity testing was complete, workers grouted the base by pumping a neat cement grout under approximately 800 psi (2.4 MPa) pressure to the toe of the drilled shaft. The CSL tubes used for this process involved coupling tube pairs at the bottom with a sleeve-port system (sometimes called tubes-a-manchette). The eight coupled CSL tubes provided four U-shaped circuits for grouting in each drilled shaft.

The load testing was the O-cell method, but we had to overcome one limitation of the technique; because of the base grouting, the axial resistance of the shaft base exceeded the side resistance available as a reaction! To provide verification to the La DOTD that the base-grouted shaft had the capacity required for the design, several load tests had to incorporate a reaction frame to help hold down the drilled shaft during testing. The test mobilized 2,000 tons (27 MN) of side resistance, plus an additional 1,000 tons (9 MN) from the reaction frame in order to mobilize 3,000 tons (27 MN) of base resistance. At that point, the side resistance of the shaft had been completely overcome, one of the reaction piles was starting to fail, and one of the reaction piles was beginning to fail, and the O-cells were reaching their limit of travel due to failure of the shaft in base resistance; every component of the system failed simultaneously, perfect!

Unique Cofferdam

The pylon foundation construction incorporated an innovative cofferdam system that used precast elements suspended from the drilled shafts. Because of the water depth during high-river stage, a conventional sheet pile cofferdam would have been difficult and risky. The drilled shafts extended to elevation +50 ft (15 m) using temporary steel casing and then the cofferdam was erected on hangers supported on the drilled shafts. The cofferdam comprised a precast system of cast-on-site elements of a size that could be handled with conventional cranes. These panels were positioned and suspended from the drilled shaft casings to provide a level working surface at elevation +44 ft (+13 m), well above the river level. After these pieces were connected, the cofferdam was completed with internal bracing, sheet pile extensions and roller guides to contact the drilled shaft casings, and the 5,000 ton (45 MN) system was then lowered approximately 47 ft (14 m) into final position using a synchronized jacking system. We constructed the footing by placing an 8 ft (2.4 m) thick concrete seal slab into the bottom of the cofferdam and then completing the reinforced footing in the dry.

Shaft excavation using oscillator

Load test setup

The contractor built the high-level approach structures on the river-side of the levees from a work trestle, with each pier on the permanent bridge supported by two columns and each column supported on a single drilled shaft. The trestle was a tubular steel structure supported on 42 in to 54 in (1.0 m to 1.4 m) diameter steel pipe piles, driven open ended. The piles near the levees had to be left in place to avoid potential disturbance of soils near the levee. The drilled shafts were of similar size as the main pylon foundation units, and were base grouted to enhance capacity. A load test shaft was included on either side of the river.

The approach structures outside the levees were generally constructed on driven prestressed concrete piles, with pile footings supporting two column piers in the higher portions of the approach structure and pile bents for low level viaduct. In some areas, we used steel pipe piles to facilitate construction in restricted headroom conditions near high voltage power lines from the nearby Big Cajun power plant. Workers installed these steel pipes in 20 ft (6 m) long sections with splices between sections.

The driven pile foundations included test piles subject to dynamic testing. In general, we installed driven piles with low initial driving resistance, and long-term measurements of setup were required to verify axial resistance.

Summary

The record-setting Audubon Bridge was La DOTD's first design-build experience, and the project team employed innovative techniques in design and construction to overcome the many challenges. The project team constructed the drilled shaft foundations in difficult ground conditions using the oscillator technique, which had never before been applied in this area and geology. With the use of base grouting, this system provided a more economical and constructible foundation than the conventional gravity caissons traditionally employed on the lower Mississippi. The extensive load testing program assured the owner that the unconventional means and methods employed on the project met the design requirements. The precast sectional cofferdam suspended from the drilled shaft was an innovative construction method to complete the pylon foundations even during high-water periods in the river.

Below: West pylon construction in foreground with high-level approach construction looking west