Spanning the Mississippi:

Overcoming the Challenges of High Voltage Electric Transmission Construction Over the River

Ameren Transmission's (ATXI) Illinois Rivers Project is a 345-kV transmission line that is part of a portfolio of projects to improve overall electrical grid system reliability and increase capacity. Routing a 385-mile transmission line is a challenge many engineers may only encounter once in their lifetimes, if at all. To route the project from Palmyra, Missouri, across Illinois to the Indiana state line, ATXI utilized existing rights-of-way and man-made boundaries as much as possible. While that strategy helps reduce project impacts, it does little to tame Mother Nature: when the objective is to improve the electrical system within a region, major rivers can't often be avoided. Transmission lines across the country must span bodies of water, including rivers and swamps. The encountered natural forces impact the design of the lines and challenge even the most advanced construction methods. Hanson Professional Services Inc. worked closely with Ameren to address the project's geotechnical, civil and foundation engineering challenges.

The project conquered three major river crossings. The most challenging was the 1.56-mile Mississippi River crossing, which includes six lattice steel structures 167 to 385 feet high. Three of the six towers are on the river side of the two levees bordering the Mississippi, and two of those were constructed on Fabius and Ward islands near the Missouri and Illinois riverbanks, respectively. This floodway condition complicated design, construction and geotechnical investigation in terms of safety, schedule, budget and permitting.

continued on next page

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All steel tripod foundation

Construction access to each tower location was the biggest obstacle. The three towers in the levee-protected zones were accessed from county roadways with matted access. The other tower that is not on an island is less than 300 feet from the Missouri-side levee. The construction of a temporary access road over the levee was negotiated with the levee district: the agreement required daily monitoring of the roadway, weekly levee inspections and a post-construction analysis.

Access to the two tower locations on islands was especially challenging. Historical data indicates the entirety of Ward Island and the majority of Fabius Island have a 50% chance of being submerged by the river in any year. How would the construction team retreat quickly and safely from rapid flooding? Public agency stakeholders required that public access be maintained through the side channels during construction, so temporary bridges, floating barges and causeways to provide access to the islands were not acceptable. The access had to come from the river sides.

The east side of the Mississippi is the deposition side of a meander at the project location, and a 600-foot-wide sandbar on the river side of Ward Island was examined, but was neither stable enough for equipment to track across it to the island, nor would it allow barges to maintain proper draft near the island shoreline. After extensive stakeholder input, a 720-foot-long temporary riprap and crushed stone access road from the tower location on the island toward the main channel of the river was designed and permitted to allow for barge unloading. The access road consisted of approximately 12,000 tons of material and necessitated a floodway construction permit, or no-rise certification, from the Illinois Department of Natural Resources.

Access to Fabius Island had an easier solution, because no sand bar is present on that side of the river. The shoreline on the river side of the island was temporarily stabilized so that steel ramps could be dropped from the barges to offload equipment and materials.

While the construction access was designed and permitted, Hanson worked with Ameren to complete the geotechnical investigation and determine the optimum foundation type. Again, the river conditions during construction were at the forefront of the team's deliberations. Delivering to or producing concrete on the islands would be problematic because of the transportation challenges from concrete plants and the flooding concerns and increased clearing and permitting that would result from on-site batch plants. A 1970s-era Ameren transmission line north of the new crossing inspired an alternative to concrete with its all-steel tripod foundations, requiring no concrete.

Therefore, an all-steel tripod configuration under each tower leg consisting of individual groups of driven steel piles was designed. Three wide-flange steel legs comprise each tripod. Two legs are battered at 1.0H to 2.5V to resist lateral forces, and the third is vertically oriented. A wide-flange steel cap beam and a group of piles driven in alignment with each leg supports each leg of the tower. Tower location and height determined how many piles were required, varying from six to 10 for each tower leg. The maximum factored pile design loads were approximately 170 kips in compression and 130 kips in tension.

The nominal pile capacity for vertical and battered piles at the foundation locations was estimated based on soil boring data collected at each location. Hanson completed 12 soil borings for the six lattice towers. Half were to a depth of about 100 feet, and the other half were advanced to about 120-125 feet, where bedrock was encountered and cored. Illustrating the access challenges, three attempts to offload the drill rig from a barge onto Ward Island were unsuccessful because of river levels and the sandbar's underwater banks, so the nominal pile capacity for the vertical and battered piles at this foundation were estimated using soil boring data from adjacent foundations and confirmed later, when the drill rig could access the site.

Temporary Access Road Across Sand Bar

Tower construction

The foundation design required HP 14X89 pile sections, but HP 14X117 piles were installed. The upsizing of the final pile sections is explained by the team's solution for corrosion protection. Heavier pile sections were selected to provide a corrosion allowance, after considering other corrosion protection measures such as protective coatings and galvanizing. Utilizing a minimum foundation design life of 100 years, the H-piles were first sized for strength (requiring HP14x89 sections), then increased to HP 14x117 to account for estimated corrosion/section loss. The design team also provided drain paths to prevent water from being trapped between the stiffeners and the webs of the cap beams. Other design details included adding cover plates to fully box the wide-flange shapes forming the legs of the tripods to protect the flange tips from localized bending due to ice and debris; oversized cap plates for additional pile location tolerance; and additional member length to allow for field adjustments when connecting the tripod members.

The design and analysis of the steel tripods and steel piles were performed using 3D design and analysis software, including the use of lateral soil "springs" to model the effect of the structure-soil interaction. The foundation designs were based on reactions at the base of each tower leg provided by the lattice tower designer, ASEC Inc. In addition to the factored base reactions (approximately 1000 kips down, 800 kips uplift, 300 kips shear), other loads evaluated included wind on exposed foundation elements and stream and flowing ice forces. The anchor tower foundation loads were generally controlled by the "NESC Heavy" (National Electrical Safety Code C2 - 2012) loading combination, with some modifications by ATXI, while the taller suspension towers were controlled by extreme wind load combinations applied at a skew relative to the line alignment. This resulted in maximum upward and downward tripod loads at diagonally opposing tower legs. The American Association of State Highway and Transportation Officials considers flowing ice to be an extreme load case with a low probability of occurrence. Therefore, it was deemed overly conservative to apply flowing ice load indiscriminately to all load combinations. Ultimately, flowing ice loads were included in all combinations that did not include extreme wind loads. For comparison purposes only, load combinations with extreme wind loads were combined with flowing ice loads, using an overload factor of 125%. The geotechnical analysis determined that neither liquefaction, nor lateral spreading caused by liquefaction, was a concern.

Also integral to the foundation design, Hanson's water resources team developed recommendations for the elevation of the top of the tripod foundations and provided scour depths for the foundation engineers' use when determining the required pile lengths. Ameren's project criteria required that the top of the tripod foundations be one foot above the 500-year flood elevation, so that up to and including such flood events, the tower legs will be above water levels carrying potential debris. The results of scour depth analyses at the foundation locations ranged from 4.1 feet to 8.8 feet, which was then considered in the foundation pile designs.

The pile lengths were adjusted in the field after actual pile capacities were verified using dynamic load testing on a minimum of two piles

continued on next page

Spanning the Mississippi continued from page 29

per tower. Dynamic pile load test data was used to confirm pile load capacity and establish pile driving criteria for the remaining production piles. Pile lengths of up to 90 feet were installed. After the piles were driven and the tripods installed, the lattice tower assembly began with crane erection of the bottom sections of the lattice towers. The upper tower sections and arms (above approximately the 200-foot level) were erected by helicopter.

The river flooded several times during construction, causing the construction team to temporarily demobilize. However, the Mississippi River crossing was completed in 14 months, including collaboration, alternative analyses, creativity, design and construction.

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