HDD UTILIZED TO COMPLETE KEY CROSSINGS FOR TRANSMISSION LINES FROM NEW WOODBRIDGE ENERGY CENTER

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ABSTRACT:

Competitive Power Ventures' Woodbridge Energy Center is a new 700-megawatt, dual energy, high efficiency power generating plant being built in central New Jersey. Located in Woodbridge, New Jersey, the plant will supply electrical power to the New Jersey metropolitan area, meeting the growing demand for power and providing increased reliability for the local grid. When plant construction is complete, power generated at this new facility will be transmitted to Jersey Central Power and Light's existing Raritan Substation, approximately three miles away.

The required three mile transmission alignment between these two locations included some critical crossings, including two environmentally sensitive wetland areas and the longest one, a crossing of the Raritan River. Use of traditional installation methods such as overhead towers and direct burial of conduit were not feasible in these sections of the required alignment. For these three critical locations horizontal directional drilling (HDD) was used to install more than one mile of transmission lines. Each of the three sections included dual parallel installations, resulting in six separate drills of 30-inch casing and conduit pipe installations that would eventually house three 230 kV electrical cables each. In all, over 11,000 feet of HDD installation was completed for these sections.

Fusible polyvinylchloride pipe (FPVCP) was used for both the casing and conduit piping. The 30-inch FPVCP casings housed four 8-inch FPVCP conduits to carry the transmission cables, two 2-inch HDPE conduits for ground and fiber optic lines, and two 3-inch HDPE grout delivery tubes. The entire assembly was grouted in place using an engineered thermal grout for heat dissipation. Local suppliers provided the materials that were tested and used for this project.

This paper will discuss the design and construction elements of the HDD sections, as well as the lessons learned for these key 'underground' sections of the Woodbridge transmission project.

INTRODUCTION

Competitive Power Ventures is (CPV) currently building a new dual energy, high-efficiency generating plant in Central New Jersey. The project, being called the Woodbridge Energy Center (WEC), will produce 700 megawatts of electricity for use in the New Jersey metropolitan area. The WEC will utilize natural gas as the primary energy source and ultra-low sulfur diesel as the secondary energy source to produce electricity. It will generate enough electricity to power more than 600,000 homes helping New Jersey meet its growing demand for energy while also increasing the reliability of New Jersey's energy grid. The project is unique, in that it is situated in a brownfields development area on the site of a former chemical plant, in Woodbridge, New Jersey. In order to tie the new WEC facility into the grid, a transmission alignment was required to connect to Jersey Central Power and Light's Raritan Substation (Raritan Substation), approximately three miles away from the WEC site (see Figure 1).

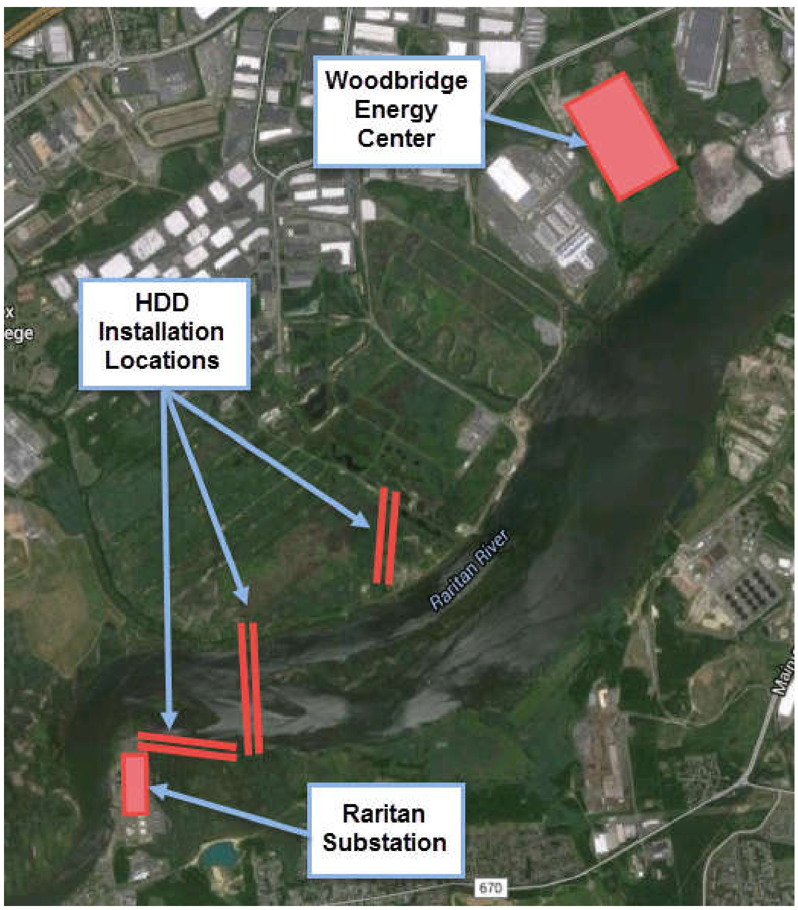

Figure 1. General location map showing location of the HDD portions of the project alignment and the Raritan Substation location.

The three mile separation of the WEC from the Raritan Substation included varied terrain and a river crossing, which complicated the required construction of the transmission cable. Due to the wetlands, river crossing and environmentally sensitive nature of the work, traditional overhead or even direct bury trenched construction was not going to be possible for the entire alignment. For these specific sections, horizontal directional drilling (HDD) technology was used to “underground” the transmission cabling in cased conduits, where project site disturbance was not an option. The entire alignment included sections of overhead, direct bury, and HDD construction in order to meet the project constraints.

Marathon Engineering & Environmental Services prepared the initial alignment drawings that were used to obtain all the local, state and federal permits for this transmission line. While the permit process was underway, several local general contractors prepared design-build proposals for CPV and their construction management firm Kiewit Construction to complete the work. The transmission line portion of the WEC project was ultimately awarded to a joint venture entity, formed specifically for this project, between a Long Island, NY electrical contractor, E-J Electric, and a large New Jersey based civil contractor, Ferreira Construction. This joint venture entity, EJ/Ferreira JV, was well suited for successfully completing the transmission line. E-J/Ferreira JV contracted with the engineering firm, Paulus, Sokolowski & Sartor, LLC, to prepare the construction documents for the traditional overhead and open cut portions of the transmission line. E-J/Ferreira JV then also procured the services of Carson Corporation to design and build the six HDD’s associated with the alignment.

PROJECT DESIGN ELEMENTS

The underground portion of the 230 kV transmission lines start about a 1/2 mile behind the New Jersey Convention Center in Edison, NJ and crosses roughly 1-1/2 miles of wetlands as well as the Raritan River. The first HDD location consisted of two parallel bores that crossed 1,500 feet of environmentally sensitive wetlands. The next HDD location included the longest installation lengths for the project, consisting of 2,400 feet crossing under the Raritan River. In between these two HDD locations, E-J/Ferreira JV installed a 1/2 mile of duct bank conduit using direct bury construction methods. The final HDD installation crossed 1,400 feet of environmentally sensitive wetlands and tied the Raritan River crossing into the Raritan Substation (see Figure 1).

The HDD portions of the project included three stretches of dual casing and conduit installations. The total alignment distance completed for the project was approximately one mile, or one third of the project length. Since each HDD segment required the installation of two casings and conduit bundles, the total length of the HDD installations required was over 11,000 feet, or approximately two miles.

Horizontal directional drilling of electrical cable is typically more expensive than traditional overhead lines, and it is imperative to maximize electrical efficiency or ampacity for the underground portion of the transmission lines. The use of plastic casing and conduit, such as polyethylene or polyvinylchloride in place of steel reduces ampacity loss and the use of an engineered thermal grout helps dissipate heat also helping with ampacity loss and extending cable life.

The Carson Corporation elected to use fusible polyvinylchloride pipe (FPVCP) as the casing and primary conduit material for several reasons. First, the tensile capacity of FPVCP provides for a thinner pipe wall for the same buckling and deflection resistance as other thermoplastic pipe options currently available. This means that the overall borehole size could be reduced by using FPVCP, but still provide the required casing and conduit inner diameter for the cable and thermal grout design. Reducing diameter and wall thickness also had tangible value for the HDD process, by reducing the size and weight of both the casing and the conduit, it lowered the risk and cost. The final design for the HDD bores included a 30-inch FPVCP casing, four 8-inch FPVCP conduits, two 2-inch high density polyethylene (HDPE) conduits for the ground cable and a fiber optic line, and two 3-inch HDPE grout tubes. Underground Devices, Inc. custom designed and manufactured casing spacers for the project that held the conduit bundle in the appropriate configuration and also provided wheels for reduced friction of the bundle during installation (see Figure 2).

Figure 2. Final conduit bundle assembly, showing the (4) 8-inch FPVCP conduits, the (4) potential 2-inch HDPE conduits (only two used), the (2) 3-inch HDPE grout tubes, as well as the casing spacers and how the configuration was banded together.

HDD CONSTRUCTION DETAILS

Construction of the HDD segments of the alignment began in early spring, 2014. Required completion of these segments was on a very tight construction schedule, requiring the entire transmission line to be completed and tested by September, 2014. To meet this schedule, the HDD's, overhead cable and direct bury work would all need to take place on the project site simultaneously. Before any of the actual drilling work could start, over two miles worth of timber mats needed to be installed, because much of the HDD work areas were in soft, swamp-like conditions. Timber mats created a stable platform to support the drilling equipment and a location to stage the assembled casing and conduit pipe prior to pull back. A 54-inch steel conductor barrel was constructed at each entry location prior to commencing with the actual drilling activities. A pneumatic hammer, supplied by TT Technologies, Inc., was used to drive 150 feet of casing into the ground at a 12 degree angle. This prevented the soft ground near the surface from collapse during the HDD operations. Once the 54-inch steel conductor barrels were installed for the first pair of HDD alignments, three maxi-sized drill rigs were mobilized to the project site. All three drill rigs are American Augers products, models DD140, DD440 and DD1100. The DD1100 is the largest, with over 1,000,000 pounds of pull back force capability (see Figure 3). To meet the demands of the schedule, drilling took place two bores at a time. Following the drill plan designed by Carson Corporation, a 12-inch pilot hole from entry to exit was created which set the alignment of the bore hole. This was followed by several reaming operations that successively enlarged the hole from 12-inch to 24-inch, 24-inch to 36-inch, and ultimately 36-inch to 48-inch. After the 48-inch hole was cut, Carson Corporation preformed one final "swab" pass to ensure the integrity of the bore hole, sweep any remaining cuttings and excavated material from the borehole, and stage clean drilling fluid for the final pull-in of the casing pipe.

Figure 3. The largest directional drill rig used for the project, an American Augers DD1100.

While the drilling operations were ongoing, Underground Solutions, Inc. was assembling and de-beading the 30-inch FPVCP casing pipe. Sections of 30-inch FPVCP were thermally butt-fused together into one continuous length of pipe. These lengths were staged beyond and in line with the exit hole of each bore. Each fused joint was internally de-beaded, whereby the raised portion of fusible material that is left after the joints are completed is removed with a mechanical cutter. This was necessary to ensure the wheels on the casing spacers for conduit bundle would not get hung up during the conduit bundle installation. The entire string of 30-inch FPVCP was pressurized with 5 psi of compressed air and pneumatically tested for 30 minutes prior to installation to ensure there was no vandalism or damage to the pipe string prior to installation.

The timing of the construction was orchestrated so that immediately following the swab pass, the 30-inch FPVCP was ready to be installed. Using a mechanical pulling head attached to the 30-inch FPVCP, installation of the entire string took less than 200,000 lbs of force (see Figure 4). To reduce the amount of pull back force needed, the casing pipe was ballasted or filled with water as it entered the bore hole. This acts to reduce the upward buoyant force created by the pipe as it moves through the dense drilling slurry, reducing the frictional forces generated as it is pulled through the bore. All of the HDD bores were completed in this same fashion.

Figure 4. Typical 30-inch FPVCP casing insertion shown with aerial support provided to guide the FPVCP into the required angle of the drill exit.

Each set of bores presented a unique set of challenges. The first set of bores contained the unknown of what this area would entail in terms of actual drilling geology. Although, relatively good geotechnical information was available to characterize the geology, the most valuable geotechnical information is always gathered from the actual drilling. The second set of bores, across the Raritan River, were the longest and had to penetrate a known rock outcropping. Using the information obtained during the first set of bores and some specialized rock tooling, the Raritan River crossings were completed as designed. The final set of bores, which set up to be the easiest at the project start, wound up being the most challenging. For the first two set of bores, there was a 40 foot wide easement to work in. These bores were designed and installed with approximately 30 feet of separation. For the final set of bores, the easement was only 22 feet wide. Further complicating this matter was the fact that the cable manufacturer, Taihan Electric Wire Co., LTD., mandated a 19 foot separation between the bores to prevent the cables from overheating. A sophisticated wire tracking and guidance system that is able to precisely locate the cutting head was used to provide the required separation between the bores while not extending beyond the easement.

After successful installation of the 30-inch FPVCP casing for all six HDD's, all the large drill rigs demobilized and the bundle installations started. Each 30-inch FPVCP casing would house four, 8-inch FPVCP conduits for the 230kV conductors, including three phases and a spare conduit, two 2-inch HDPE conduits for the ground conductor and a fiber optic communication line and three 3-inch HDPE pipes to serve as the grout delivery system. As with the 30-inch casing, four strings of 8-inch FPVCP were fused, internally de-beaded and staged for installation near the 30-inch casing. A similar process was also performed for the 3-inch HPDE grout delivery pipes. However, since these pipes were sacrificial for the grouting process, there was no need to de-bead each fused joint. Conversely, the 2-inch conduits needed for the ground and communication lines required a smooth internal wall. Using HDPE as the material for these conduits meant that it could be sourced on reels which matched the required length of each bore. Therefore, no joining or de-beading of the 2-inch conduits was required.

It was estimated that approximately 10,000 lbs of pull back force would be required to install the conduit bundle within the 30-inch casing. Instead of using a much larger drill rig, a Vermeer 10x15 directional drill rig with over 10,000 lbs of pull back capacity was used to more closely match the expected pull force estimates. The Vermeer 10x15 drill steel was threaded through the 30-inch casing and each conduit was independently attached to the drill steel. All the conduits were bundled together using stainless steel banding and custom fabricated casing spacers, one every five feet. With just the Vermeer drill rig and a small excavator on the insertion side to help guide the bundle into the 30-inch casing, each bundle was pulled into their respective casing with very little effort. The actual pull back force needed to install the entire bundle for any given insertion never exceeded 1,000 lbs as registered at the drill rig.

THERMAL GROUT DESIGN AND CONSTRUCTION

The purpose of thermally grouting underground installed electrical conduits is to remove heat generated by the transmission of electric power. Heat generated during electrical transmission increases the resistance and thus increases power loss. Additionally, removing heat effectively increases the lifespan of the cable insulation and the cable itself. Overhead wires have constant air cooling. Underground, there is no air circulation, thus another method of heat removal is required. Thermal grouts permit the transfer of heat from the cables into the surrounding soil. The science behind thermal grouting has been around for several decades, but long distance thermal grouting did not become a reality until approximately 2006 (Dickes, 2007; Irani et al., 2007; Dickes and Parmar, 2008).

The advent and increased use of cement admixture technology opened the doors to improved control and behavior of cementitious products. Extended working times, improved flow characteristics and improved grout stability proved very advantageous for the WEC project.

The six, long, cased HDD sections for the WEC project would be comprised of a very tight conduit bundle, meaning that there would not be a lot of space available between the conduits and casing for the grout to flow and fill all voids. This makes the project difficult in applying thermal grout technology. The tight bundle configuration posed two distinct issues. First, there would only be two small, 3-inch grout conduits from each end to work with. Second, the tight bundle arrangements only provided narrow grout flow paths to properly distribute the grout mix. This project would require a very fluid, homogeneous grout to be developed and applied.

Three primary factors need to be considered during thermal grout development. The first is the required, final thermal properties which must meet or exceed the required performance criteria. The second is constructability or the ability to deliver the grout and fully encapsulate the conduits. The third and final factor is cost.

Constellation Group, LLC (CGLLC), the grout specialist for the project, undertook the grout development process. Combining admixture knowledge and the use of specialty silica products, an initial thermal grout was developed. The basic grout components are cement, silica, water and admixtures. In terms of conducting heat, silica, including sand, performs the best, followed by cement, then water. Air is not desirable since it is a thermal insulator. Generally, air content per typical standards (ASTM C231, 2014) is a maximum of 2%, but grouts having 0.5%, or less air, are that much better. Less air means more solids and better thermal conductivity.

Thermal grouts have to perform mechanically during the placement phase. Too much silica produces a grout that is difficult to pump and will segregate during placement, or will “sand-block” the grout piping. A proper balance in the mix design must be established for optimum placement performance. Silica products run from coarse or concrete sand to masonry sand, fine natural sands, less than 250 micron, and silica flours, 50-125 micron, with costs increasing as the grain size becomes smaller. For WEC a fine natural sand was selected as meeting the best overall conditions for the project, including balancing the cost of materials. After the grout mix was formulated, samples were submitted to Geotherm, USA (Geotherm) for thermal resistivity testing. Further refinement of the mix design produced a grout with the required thermal resistivity. The required minimum thermal resistivity was 120º C-cm/W, with a preferable requirement of 90-100º C-cm/W. There was no stated moisture content percentage, so zero moisture content was assumed. Grout in an HDD, cased environment does not reach an absolutely dry condition as there is no place for moisture to migrate if the casing is properly sealed. Typical residual moisture levels are estimated at around 6%. The thermal dryout curve shown in Figure 5 shows the thermal resistivity of the grout mix at different moisture levels.

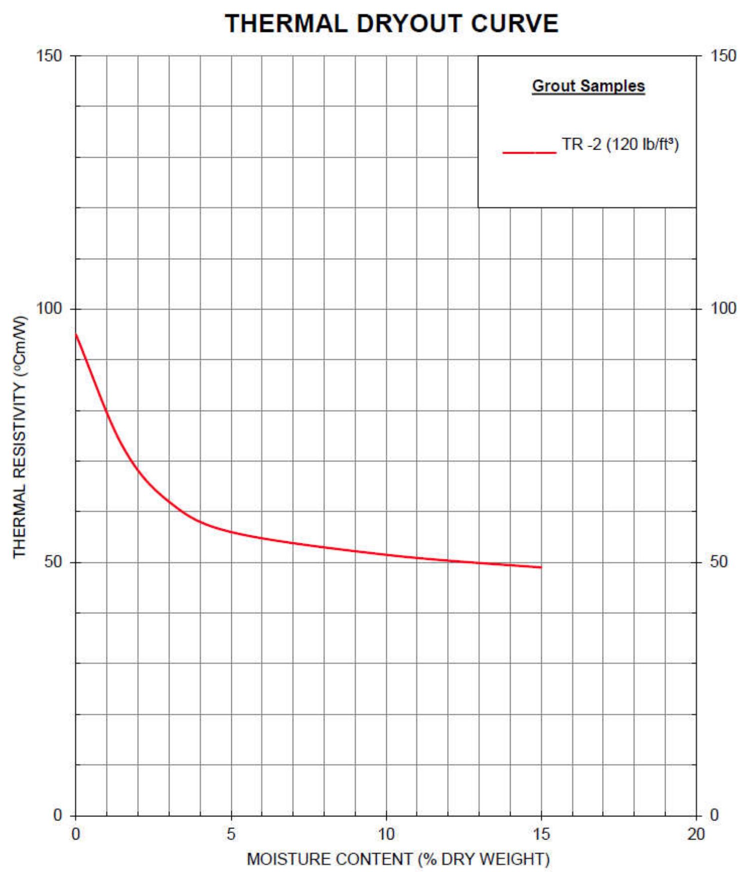

Figure 5. Thermal dryout curve test results for a sample, showing thermal resistivity with varying moisture content. Figure courtesy of Geotherm and CGLLC.

Carson Corporation self-performed the grouting operations with CGLLC's guidance for the actual grout mixing and placement. A locally sourced fine sand was selected for use on this project; however, this product was not compatible with the local ready mix supplier's equipment. Therefore, a hybrid method of batch mixing was utilized as follows:

1.) The ready mix supplier loaded his trucks with the prescribed amount of water, cement and certain admixtures.
2.) When the trucks arrived on site, 15,000 pounds of the specialty fine sand was loaded, along with a final admixture and additional water (see Figure 6).
3.) After the truck was fully loaded, samples were taken to ensure the final mix met or exceeded the designed specific gravity of 128 pounds per cubic foot (pcf). Average unit weights were approximately 130.5 pcf as measured.
4.) In total, over 2,120,000 pounds of fine sand was handled in this manner.

Figure 6. Addition of sand on-site as part of the hybrid grout batching arrangement for the project.

This process created a very fluid grout, with an efflux time (ASTM C939, 2010) of 16 seconds. The use of stabilizers in the mix prevented segregation. The tight configuration of the bundle, further complicated by the small 3-inch nominal grout pipes, limited the grouting process to an average of 24 cubic yards per hour. Pumping pressures, as monitored, were 175 psi on the pressure stroke and near zero on the off stroke. The pressure of 175 psi is misleading, as the pressure gauge was located upstream to the pump hose reduction to the 3-inch grout pipe. Downstream pressure was near zero the entire time, except for the hydrostatic pressure of the grout. Very fluid grouts should not build up around the duct spacers or develop back pressure.

As a standard operating and safety procedure, all conduits were filled with water and pressurized. This serves two purposes. The first is to act as a safety factor against unforeseen grouting pressure spikes; and the second is to act against any heat build-up on the conduits from cement heat of hydration. Many mix designs incorporate heat of hydration control, either through material selection, admixtures, or both.

In total, over 1,350 cubic yards of thermal grout was pumped into the casings. Over 90% of all grout pumped was through the 6 primary, centrally located grout pipes installed in each bundle configuration. Approximately 50 feet near the end of each casing was left ungrouted. This allowed for final excavation and laydown of the casings and conduits to their final elevation. After connection to the respective vaults and tie-ins, the casings were topped off with thermal grout. Grouting was completed in seven, non-consecutive days. The first 1,400 LF casing required two days to complete, due to grout delivery issues with the ready mix supplier. Thereafter, each casing was completed in one day.

PROJECT RESULTS AND CONCLUSIONS

The HDD portion of the transmission alignment was completed on time and within budget. The rest of the transmission alignment portions were also completed within the required timeline. Work on the actual WEC facility continues.

Several records were set on this project in regards to the HDD portions performed and thermal grouting. These are to be considered informal as there is no one agency or institution, other than the personnel performing these tasks, overseeing or maintaining any records. For thermal grout application in sheer volume, this was the largest thermal grouting project to date, including 1,350 cubic yards. This was also the longest total footage of thermal grout installation for one project, including 11,000 feet of thermally grouted casing and conduit bundle.

This project is a good example of how a specialized team of experts and construction professionals can work together to construct a unique project in a successful and efficient manner. The design-build delivery assured that design and construction were in agreement and were realistic.

Long distance thermal grouting is a developing field. Each project has different requirements and only experience, and often times, mock-ups, can provide the correct path. On this project, a trial truckload of grout was batched and dictated a change in delivery quantities. The trial also demonstrated the grout was very fluid and stable and suitable for this project. The hybrid batching plan was also a unique solution to project location, cost and material constraints.

This was the first project in the project team's experience to utilize a fine, natural sand, which proved to be the right choice for this project. However, this may not be the correct material for other projects. Planning well in advance and working with suppliers and contractors is a necessity when it comes to designing thermal grouts to meet the needs of individual projects.

REFERENCES

ASTM C231/C231M-14 (2014), "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," ASTM International, West Conshohocken, PA, 2014, www.astm.org.

ASTM C939-10 (2010), "Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)," ASTM International, West Conshohocken, PA, 2010, www.astm.org.

AWWA C905-10 (2010), "Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 In. Through 48 In. (350 mm through 1,200 mm)" American Water Works Association, Denver, CO.

Dickes, Guy (2007), "From a Deep Hole to Success," Trenchless Technology, May, 2007.

Dickes, Guy and Parmar, Deepak (2008), "Thermal Grouts Go the Distance," Transmission and Distribution World, January, 2008.

Irani, Spenta et al. (2007), "Crossing Lake Austin Using Horizontal Directional Drilling," American Society of Civil Engineers, conference proceedings, ASCE Pipelines, 2007.