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**Record Setting Dual Casing Crosses Indian River by HDD**

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**1. ABSTRACT**

The Indian River crossing project was one portion of a 13.65-mile alignment for new, redundant 230 kV underground electric transmission lines. Multiple installation methods were required throughout the project, including open cut trench excavation, three microtunnels, and five separate horizontal directional drills. Of the installations, the most significant and technically challenging were the record breaking dual 7,020-foot Indian River casing crossings installed using horizontal directional drilling.

The casing for this installation needed to be non-conductive, safe, and economical. Installation had to be as minimally disruptive as possible as the pipe would be aurally navigated through 900-feet of protected mangrove and floated 4,500 feet through a lagoon. The casing used was 32-inch DR21 fusible polyvinylchloride pipe inserted into a 46-inch reamed bore hole, completed using intersect drilling by a 1,300,000 pound capacity HDD rig and a smaller 140,000 pound rig.

The challenges of the assembly, handling, and installation of the two 385 ton casings, the full scale testing of the 30-inch internal diameter casing, and the onsite measurement of drag forces to establish intermediate fusion lengths, are discussed.

**2. INTRODUCTION**

The unstable nature of severe weather runs counter to the need to increase the stability of the national power supply. In areas that regularly face severe weather, such as hurricanes, tornados, and earthquakes, maintaining access to a steady source of power is imperative. A lack of electricity can hamper relief and recovery efforts while exposed downed lines can be an additional source of danger. By increasing redundancy in their delivery lines, power companies are able to provide improved service to their customers in an increased number of potentially dangerous situations.

An area that is particularly susceptible to severe weather is the peninsular state of Florida. Both coasts are regularly affected by "hurricane season" and can suffer significant damage to both public and private property each time severe weather systems pass through. That damage may stem from high winds, flooding, a combination of the two,



Figure 1. Map of the Indian River Lagoon System

or their after-effects, such as fallen trees. In an effort to reduce the impact caused by such events on the local power supply, a Florida based power company began a project to install a new redundant line.

One of the best ways to ensure that the power supply stays live during weather events is to route the power underground. The main supply on a day-to-day basis may be transmitted through traditional overhead lines while the backup supply is run through underground conduit. A major benefit of maintaining power below ground is a reduced exposure to the elements; if there is a windstorm or an above ground weather event, the below ground supply will usually be unharmed if installed at a great enough depth, similar to the manner of how many emergency shelters are located in basements or in specially dug out areas. The surrounding ground provides a natural stabilizing barrier against movement and temperature that would be otherwise difficult to achieve.

The overall length of the anticipated project was approximately 13.65 miles. The cross-linked polyethylene cables in the new underground conduit alignment would provide power from the main power station to a smaller substation. At the start of the alignment, there was a natural barrier that had to be crossed in order to complete the connection; the Indian River (See Figure 1).

The Indian River is a part of the Indian River Lagoon system, which itself is part of the Atlantic Intracoastal Waterway. This waterway begins in Boston, Massachusetts and runs southward down the east coast, around the tip of Florida, to end in Brownsville, Texas. The Atlantic Intracoastal Waterway is an extensive connection of waterways developed through the connection of naturally formed and manmade salt and fresh water bodies. This connection of waterways is used to provide a safe travel route for recreational vessels as well as a protected shipping

route to transport goods between the Northeast and the Gulf Coast. The Indian River Lagoon in particular is very biodiverse, boasting thousands of species of plant and animal life specific to its area. It stretches from the Ponce de León Inlet to the Jupiter Inlet. The river itself, technically considered a lagoon, is 121 miles long and was originally named the Rio de Ais after the Native American tribe who controlled the area surrounding it.

In order to safely pass through the ecologically significant area, it was determined early on that the conduit should pass below the river rather than running along the floor. This would provide a greater degree of safety and would minimize interference with the flora and fauna. The power passing through the cables housed in the conduits would be approximately 230kV. In the unlikely happening of a catastrophic event, having the power lines below ground would provide a greater degree of safety until the issue could be resolved. With all of these safeguards in place, the ability of the power company to maintain service to as many customers as possible even during major weather events would increase considerably.

### **3. DESIGN**

The design work was performed by Power Engineers, Inc. out of St. Louis, Missouri. Horizontal directional drilling (HDD) was chosen as the best option for the crossing as it would cause the least disruption. To meet the electrical design requirements, the materials used for the casing as well as the conduits would need to be non-conductive. This meant that the engineers were limited to working with plastic piping. As an option to decrease the difficulty of the conduit installation, butt fused pipe was permitted in the specifications for bid. By eliminating the gaskets necessary for pipe assembled with interlocking pieces, the conduit bundle would have a great deal less resistance moving down the length of the pipe at the end of installation. This did mean that if fused pipe were to be used, the internal bead formed during the fusion process would need to be removed as to limit damage during the cable and conduit installation.

The plan for the cable layout of the entire 13.65-mile project was to have the new dual underground cables run parallel to the three existing overhead cables that are the primary power supply. The alignment would deviate during the river crossing, travel through an existing corrido towards the turnpike, be installed by pipejacking below the railroad, and then match back up with the overhead lines until it reached the termination at the substation. The entire transmission alignment would consist of cable installed in underground conduits. The Indian River crossing would consist of dual 7,020-foot casings that would be pulled in one at a time to minimize disruption to the surrounding area. A longer casing installation was initially desired so as to allow the cables to continue uninterrupted for as long a distance as possible, but the high voltage power cable manufacturer limited the cable length to 7,000-feet due to concerns about the tensile loading during its installation and physical limitations in transporting and deploying a single cable at this type of length.

The river crossing required a casing to first be installed due to the length and depth of the installation. The other seven crossings did not require casings because of their relatively short lengths. There were a total of four additional HDD installations on the project as well as three crossings completed using microtunneling methods.

Due to the ampacity requirements of the project, a non-metallic casing and conduit pipe had to be used. After consideration of the estimated pull loads, it was determined that the only non-metallic casing material capable of successfully being installed by HDD of these parameters for the Indian River crossing would be fusible polyvinylchloride pipe (FPVCP).

Among the most difficult challenges to designing the full alignment of the river crossing were the constraints of working within the mangrove forest. The Florida Department of Environmental Protection permit allowed only 2,000-square-feet of mangrove trees to be removed to make way for the new pipe. To maximize the effectiveness of this limitation, the alignment followed an existing pathway through the trees, which would allow the machinery to be moved in and set up with minimal impact.

The casing would also need to be floated out on a lagoon prior to the aerial crossing of the mangrove forest. This required a number of environmental factors to work in favor of the project, as any inclement weather could negatively affect the pull in process (See Figure 2).



Figure 2. Complete project's anticipated alignment

The sheer length of the installation was also a difficult factor in the design. The project would require a great deal of skill to be completed successfully. To ensure this, the requirement for the driller on the project was to have had previous experience with a 6,400-foot minimum drill and the project manager supplied by the general contractor had to have completed at least three projects of similar size.

The design called for four smaller 10-inch diameter conduits that would hold the power cables to be installed within the casing after the installation of both 30-inch casing pipes were completed. At that point, each casing pipe would be filled with thermal grout to allow for adequate heat dissipation.

#### 4. PROJECT BIDDING AND CONSTRUCTION

The bidding process was particularly difficult for this project. In order to ensure that the project was installed correctly and successfully, a stringent qualifications requirement was put in place. This limited the bid to a fairly small number of contractors and drillers, a number that was further limited by the fact that many were concerned about attempting such a long HDD crossing with a plastic product. At the time of award, the project was let to a single general contractor with the exception of the Indian River Crossing, separating the project into two independent sections. After a lengthy evaluation process, it was decided to award the Indian River Crossing to Mears Group, Inc. (Mears), who would function as both primary driller and general contractor. Mears had offered a comprehensive bid and brought its extensive experience working with both long drills and FPVCP. They offered a background of having completed a drill of similar length using steel pipe and one of similar length 16-inch FPVCP, though the longest HDD they had completed with a 30-inch FPVCP was 3,000-feet, which was the longest HDD installation of that size FPVCP by any drillers to date. This project would be a considerable step up in complexity and risk.

Little guidance was offered by the design team regarding the HDD installation. The majority of the installation requirements instead came from the electrical engineering consultants. Their requirements, however, were primarily concerned with power requirements of the electrical system, allowing the HDD contractor to develop their own execution plan.

The alignment of the HDD crossing itself was fairly straight forward. The pipe layout leading up to the installation, however, was a different story. A 100-degree turn had to be accomplished from the initial fusion point to the installation point, all while traversing land, sea, and air. Mears was solely responsible for ensuring the pipe successfully made it from initial layout to completed installation. Since the project was moving at a fast pace to meet the deadlines set, there wasn't much opportunity to develop an extensive plan that would cover everything to be done from start to finish. Instead, processes for each phase of the project were developed as needed. Processes for the next phase were developed concurrently with the execution of the previous phase.

To prepare for initial pull in, the 30-inch FPVCP casing was fused using two McElroy T-900 machines. To fit into the space available along the road where fusion was occurring, both casing strings were split into three sections, the longest of which was 2,520-feet. Two intermediate fusions were required, using a McElroy 1648 machine, to connect each full string into a single piece. The larger 1648 machine was used for the intermediate fusion joints to compensate for the increase in drag during the fusion process due to the weight of the joining pipe length. Both machines were operated by a single fusion technician.

Each assembled casing length weighed 385-tons, or 770,000-lbs. In order to facilitate the easiest movement of the pipe and to protect the pipe during both fusion and installation, an extensive roller layout was created. The rollers were spaced 55-feet apart to control the sagging of the casing during fusion and pull back with temperature changes taken into account. (See Figure 3) There were some concerns about how well the mobilization of the pipe would go once movement began due to the close proximity of the assembled pipe lengths. Movement of the first assembled length went fairly smoothly and lessons were learned that allowed the second assembled length's installation to be even easier, such as how the rollers might be adjusted to ensure easier movement as well as a refined lifting technique in order to move the assembled length and individual delivered pipe lengths into position on the fusion machine.



Figure 3. Assembled casing layout on rollers along the west shoulder of A1A.

The first movement of the pipe from fusion to installation was from its layout area to the edge of Big Muddy Creek. No public roads had to be shut down during the pipe transport, so there was virtually no impact on the public, other than seeing the fusion process occur on the west shoulder of the A1A highway. From the edge of the creek, the casing was sliplined through a 2,160-foot HDPE culvert that had been placed at the necessary curve by a series of piles driven into the creek bed in 50-foot intervals (see Figure 4, left). Mears was surprised by the actual depth of the creek versus the expected depth. They had anticipated the creek to be about as deep as the river, around 8- to 15-feet. In actuality, the creek was about 40-feet deep in some areas due to prior dredging. This necessitated a change to the design of the pilings, which used a stiffer material to compensate for the additional depth. From start to finish, the culvert created a 100-degree horizontal curve through the lagoon.

The second movement involved the casing being floated approximately 2,100-feet from the end of the culvert, crossing the intracoastal inlet, to the edge of the mangroves. This alignment was mostly straight and there was little

guidance needed for the casing pipe beyond a few more pilings, now spaced at 300-feet, sunk into the creek bed (see Figure 4, right). The pipe's movement was continuous from the end of the culvert into the open water, so the same winch based pulling method used to move the pipe through the culvert was used to move the pipe towards the island.



Figure 4. (left) FPVCP casing prepares to enter HDPE culvert. (right) FPVCP pipe exits culvert, floated across creek.

The third movement, and the most challenging, was the aerial crossing of the mangrove forest. A certified mangrove tree trimmer was brought in to determine what areas could be trimmed. Though there had been a limit of 2000-square feet of tree that could be cleared, significantly less was actually removed. As such, it was incredibly difficult to move the machinery needed for the installation onto the small island. The roads used to access the exit work site were narrow maintenance access roads; they were not paved or treated and were not designed to support heavy machinery.

Mears had initially considered a series of temporary structures being built through the mangroves that would support the casing while the installation process began. This scheme was replaced with six cranes precisely located on either side of the path to ensure the most efficient curve was created for the pipe to travel over the full length of the mangrove without causing any damage to the trees while also making a slight horizontal change in direction. The cradles held by the cranes were spaced along the access road in manner to smoothly raise and lower the casing along its approximately 900-foot long path (See Figure 5, left).

In total, each casing took about five days to move from initial fusion layout to the edge of the mangrove, where it was then ready for installation.



Figure 5. (left) Cranes were used to cradle, align, and direct the pipe above the mangrove area. (right) Pull head used to install both casings.

A custom 30-inch pull head was created for this particular project, modeled by finite element analysis (FEA) before fabrication (see Figure 6). Before it was released to the project site, a full scale tensile strength test was conducted at Stress Engineering in Waller, TX. The test protocol used in this particular test was developed to simulate difficult HDD pull conditions at high loads. A cyclic load application was used with load ramping up over a two-minute period, followed by a hold period at load for 15 minutes, and a ramp down. A wait period of 4 minutes was used and then the full cycle was repeated. The cycle replicated the type of time periods for a drilling rod pull and change out. Loading started at 300,000-lbs then ramped up in 50,000-lb increments to maximum load. The allowable tensile load for the 30-inch DR21 casing is 408,000-lbs. The cyclic loading test reached 840,000-lbs at failure (see Figure 7). The FEA predicted failure at the pull head connection blot furthest from the casing end where the pull head attached. Actual failure occurred where the FEA predicted, confirming the strength of both the pipe and the pull head connections.

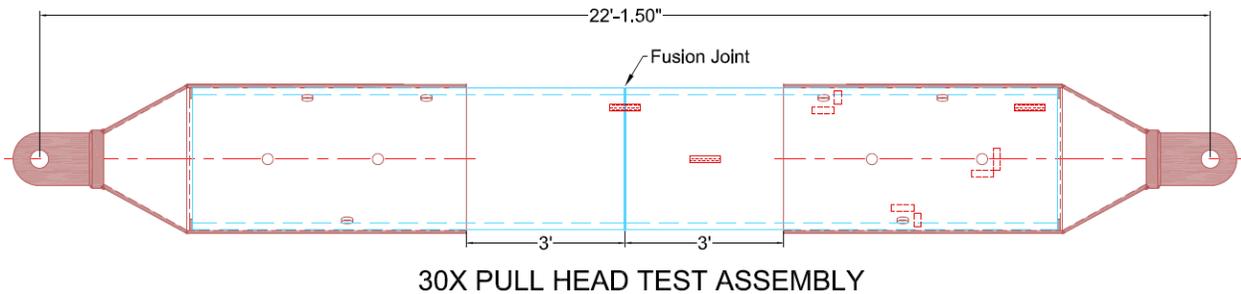


Figure 6. Pull head test assembly utilizing two pull heads, 30-inch DR21 casing, and fusion joint

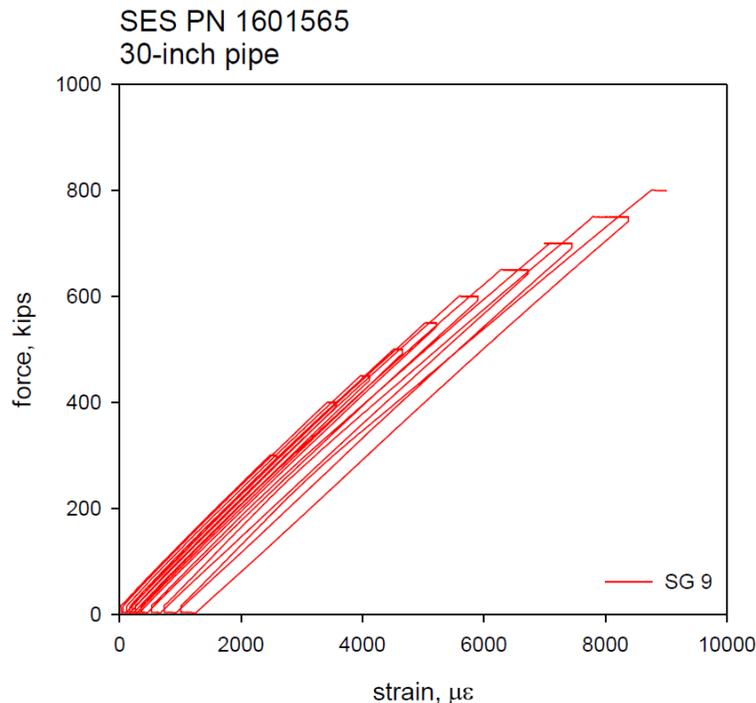


Figure 7. Stress/Strain plot by Stress Engineering for pull head tensile test as measured via strain gage

Two HDD drill rigs were used on the project. A 1.3-million-pound rig was selected as the primary HDD rig. Another smaller 140,000-pound rig was also used on the exit side. The pilot hole was drilled from both sides and intersected at roughly the midpoint of the crossing. The hole was then reamed in three stages: 26-inch, 36-inch, and 46-inch before swabbing and pullback. No incidents were recorded during the initial reaming, and after the first swab, the hole was declared fit for installation. A PVC pipe installation of this magnitude had not been attempted before so there was concern about the actual pull loads that would be needed, considering the route from the fusion

area through the HDPE culvert, through the lagoon and over the mangroves while traversing a 100-degree horizontal curve. Through on-site testing and calculation of the expected drag forces, an estimated pull load was used to monitor the real time forces as the casing was pulled. Though there was no worry that the rig would be able to pull back the casing successfully, there was some concern about managing the casing along its 7,020 path to the insertion point. In the end, however, the pipe went in as well as could be hoped, a testament to the quality of the borehole prepared by Mears. Each assembled length took approximately two days to install. The pull loads for each crossing were consistent with the estimated forces and ranged from 125,000 to 320,000-lbs with a few areas reaching 400,000-lbs near the end of one of the pulls. (See Figure 8)

No testing was required for the casing, as it was intended only as a means to install the cable conduit.

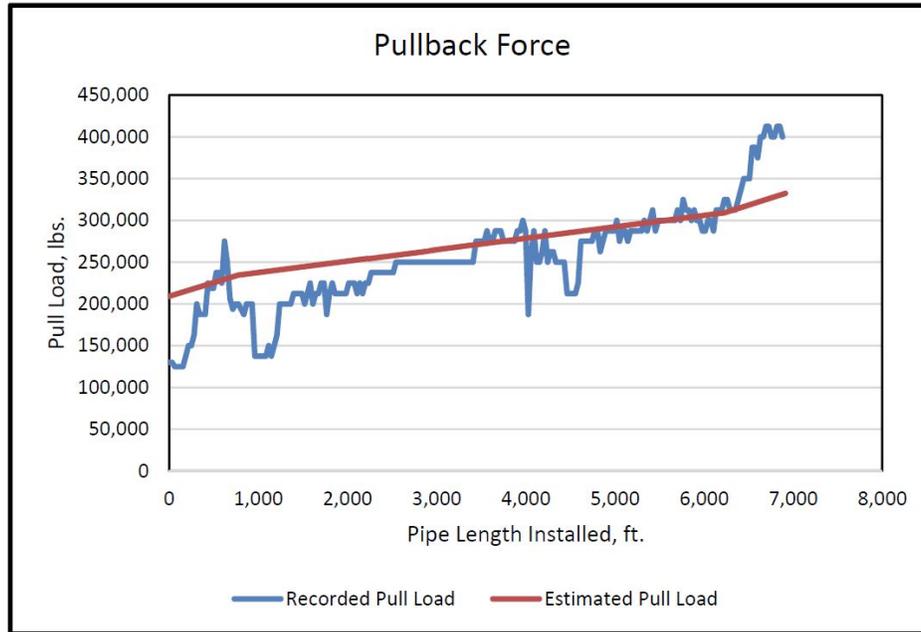


Figure 8. Average pullback force during installations

## 5. MEARS' INNOVATIVE THERMAL GROUT

The complex nature of this project led to an innovative approach to meeting the project requirements for the thermal grout. Typically, the thermal grout is pumped into the annular space between the conduit and casing through the use of tremie or grout pipes. The tremie pipes are usually pulled with the conduit bundle at various lengths so grout can be discharged at several locations within the casing for even and complete distribution throughout the pipe. Due to the extended length of this crossing, there was considerable concern that this method could achieve a completely filled annular space. Adding to the difficulty was a very limited annular space for the grout pipes so increasing their number was not a solution. A third complicating factor was the nature of the conventional grout which is based on a cement grout which has a limited duration in a fluid state before it sets. Even using additives to extend the time the grout would take to solidify was considered a severe obstacle to success. Furthermore, continuous work was not permitted and hence the grouting operation had to be suspended for twelve hours each night.

The first problem to solve was finding an alternative to the cement-based grout design so that more time was available to pump the fluid into the casing and ensure a complete fill of the annular space. A non-setting fluid was needed so that the installation could occur over a number of days as continuous 24-hour per day operation was not allowed. Through a number of iterations, a fluid was developed, No-Set™ grout, that achieved the required thermal and fluid properties while avoiding the use of cement. This would allow the fluid to be installed over a number of days if necessary without the risk of solidifying as a cement-based grout would.

The second problem was how to install the grout into such a long casing. Many ideas were discussed but the approach selected was one that had not, to Mear's knowledge, ever been attempted. In this scenario the fluid would be pumped into the 30-inch FPVCP casing before the 4 x 10-inch and 2 x 3-inch conduit bundle was installed. The fluid would completely fill the 30-inch casing, then, when the conduits were pulled through, they would displace the fluid, leaving no air gaps. This approach was considered far superior to other options with respect to the final product achieving acceptable thermal and electrical performance. However, there were challenges to overcome, such as pulling 10-inch DR9 HDPE pipe through 7,000 feet of a heavy, viscous fluid. The unit weight of the fluid was about 12.8 lb/gal which resulted in a very high buoyant weight for the pipe thus greatly increasing the frictional drag when pulling the pipe. To offset this buoyant force and reduce the drag, the pipe was left open ended to allow the fluid to enter the pipe and self-ballast as it was pulled through the casing. This method allowed the 10-inch conduit bundles to be successfully pulled through the 7,000 feet of fluid filled casing pipe. Each conduit was later cleaned out and tested for deformation with successful results.



Figure 9. FPVCP casing during installation across inlet.

## 6. CONCLUSION

This project was an enormous feat of engineering both from a technical and practical standpoint. The length and heft of the casing pipe strings places the project among the top HDD installations successfully attempted; it is both the longest thermoplastic HDD installation of any diameter as well as the heaviest single installation of FPVCP. Furthermore, the nature of the thermal grout used, as well as the volumes and distances of thermal grout placement were all unique. In September, the installation was named Trenchless Technology's New Installation Project of the Year 2016 winner.

## 7. REFERENCES

Florida Department of Environmental Protection – Figure 1 image from “Description of Mosquito Preserve Aquatic Lagoon”, last updated April 06, 2015

Trenchless Technology (2016) – *Trenchless Technology Announces its 2016 Projects of the Year Winners*