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Volume 57 2nd Quarter 2014

PowerSouth's World Record Breaking 115kV HDD Installed Underground Transmission Line Feeding Orange Beach, Alabama

Part 2 of 3 - Horizontal Directional Drill and Termination Structures

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Horizontal Directional Drill

Southeast Directional Drilling was awarded the HDD contract which included backstring fabrication, the horizontal directional drill, backstring pullback and grout placement between the HDPE pipe and the 36" diameter steel casing.

As discussed in Part 1, the only technically acceptable route between Sapling Point and the Florida Avenue Substation required directional drilling under the energized 115kV Florida Avenue Substation.

However, before directional drilling could begin, a 60-inch diameter, 220-foot steel casing was installed under the substation and extending beyond the substation limits. The purpose of this casing was to minimize operational impact to the substation during directional drilling and backstring pullback operations. A 60-inch casing diameter was selected to allow the 48-inch diameter reamer required for the borehole.

The substation was de-energized as a safety precaution during installation of the 60-inch casing with substation equipment monitored throughout the process and tested to ensure the substation could be safely reenergized upon completion. Installation of the 60-inch casing was the only time substation de-energization was required and it was coordinated with the substation upgrades needed to accept the new 115kV transmission line.

While the 60-inch casing minimized risk to the substation throughout drilling and backstring pullback operations, drilling under an energized substation created its own set of challenges, in part by direct contact of the steel casing with the substation grounding grid. Connecting the

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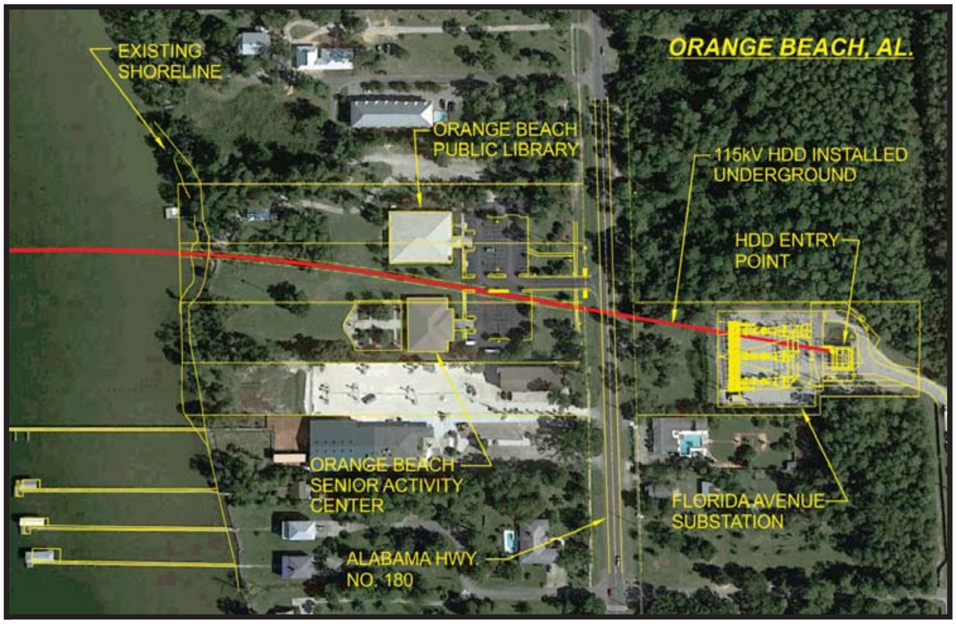


Florida Avenue Substation Area HDD Plan

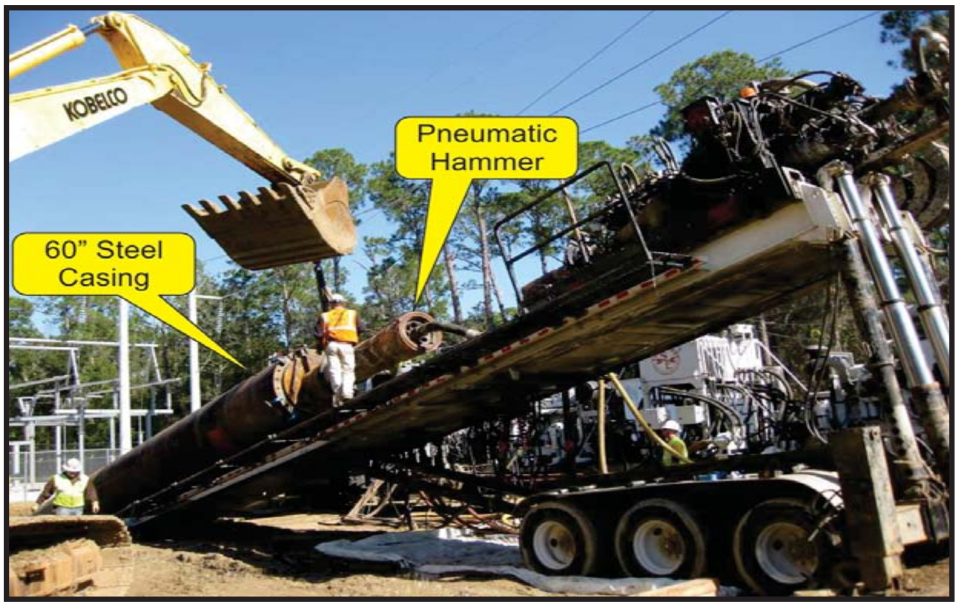
Note: The route required drilling under Florida Avenue Substation, Alabama Highway 180, as well as between the Orange Beach Library and Senior Activity Center before reaching Wolf Bay in its 6, 131-foot trek to Sapling Point located on the mainland north of Orange Beach.

substation grounding grid to drilling equipment located on both sides of Wolf Bay via the drill string created a personnel safety concern that had to be addressed. The concern was that an electrical failure within the substation, along the 115kV transmission lines, or a lightning strike to either the substation or transmission lines, would create a personnel electrical shock hazard. Electrical failure or lightning strike events could raise substation ground potential and create an electrical shock safety hazard to anyone working around the drilling or cable installation equipment unless protected by a similar substation grounding system. To eliminate this hazard, a temporary ground grid designed to IEEE 80 "IEEE Guide for Safety in AC Substation Grounding" standards was installed under each worksite with all equipment bonded to this temporary grounding grid. This ensured any event raising substation ground voltage would not create a shock hazard to personnel working in the area.

Once the 60-inch casing extended beyond the boundaries of the substation, soil within the casing was removed by a 42-inch diameter auger connected to the drill rig. After the soil was removed, a 16-inch "centralizer pipe" was placed inside the 60-inch casing to center the drill string during pilot-hole boring as well as following ream passes required to enlarge the bore in preparation for pullback of the 36-inch steel casing.

One challenge created by the extremely long directional drill was steering capability of the drill after approximately 4,000-feet or so depending on soil conditions. The longer the directional drill, the more difficult it becomes to make changes in bore direction. Since the Wolf Bay crossing required 6,131-feet of directional drill, this concern was addressed by drilling from both sides with drill bits meeting close to the middle or approximately 3,100-feet from each end.

The Sapling Point drill rig had a pullback capacity of 625,000 pounds, since it was only required to drill one half of the pilot hole length and pull back the 4-5/8 inch drill string, while the Florida Avenue Substation drilling rig had a pullback capacity of 1,100,000 pounds, since it would be required to pull back the entire 6,200-foot length of 36-inch steel casing. Both drilling rigs used standard 4-5/8 inch diameter drill pipe of nominal 30 foot lengths with typical API drill pipe



60-inch Casing Installation Under Florida Avenue Substation

Note: approximate 40-foot lengths of 60-inch diameter, 5/8" thick steel casing were placed on the HDD sled to match the drill entry angle and were installed using a pneumatic hammer. Upon completion of each pipe section, an additional section was welded to the installed pipe until the 60-inch casing extended beyond the substation's north boundary.

16-inch Centralizer Pipe in 60-inch Casing

couplings. The drilling operations also used oil well type drill bits with a 1-1/2° bend in the length of drill pipe located just behind each drill bit. Each drill bit had three mud jets set 120° apart with one of the mud jets intentionally plugged. Shims placed behind each drill bit during installation aligned the open mud jets with the 1-1/2° bend in drill pipe. The pipe bend and drill bit mud jets were then calibrated with an instrument in the drilling rig control room to indicate the direction of the bend and open mud jets allowing directional steering of the drill string.

Each horizontal directional drilling rig was similar in function to an oil drilling rig, but mounted on a flatbed trailer chassis. The trailer was elevated to create the 12° entry/exit angles required by the design at both Sapling Point and the Florida Avenue Substation. Each drilling rig was also supplied with a separate hydraulic pump unit to power a hydraulic motor for rotating the drill string, a hydraulic motor for the push or pullback of the drill string as well as a set of chocks to tighten and loosen each pipe joint.

In order for the drill bits from each drilling rig to meet in the middle, the precise location of each had to be known at all times. This was accomplished by placement of magnetometers and accelerometers just behind each drill bit and connection to instrumentation in the driller's room via a single 10-AWG conductor. As each length of drill pipe was coupled to the drill string, a length of 10-AWG wire was drawn through the drill pipe and connected with a waterproof joint to the previous wire in the drill string.

The magnetometers located behind each drill bit were capable of detecting the magnetic field of the earth and were used to calculate the location of the drill bit as each drill pipe section was added to the drill string. Typically, a loop of wire with DC current would be used near the entry/exit sites to develop an artificial magnetic field where accuracy is paramount, since the earth's magnetic field can become distorted by large ferrous metal objects or electric fields. However, since the Wolf Bay crossing required two separate drill strings to intersect near the middle of the borehole, the exact location of each drill bit had to be known throughout the entire length to allow the two drill bits to meet. This required placement of a wire loop between each entry/exit location with DC current passed through the loop to create an artificial magnetic field throughout the entire length of the borehole that could be detected by the magnetometers and used to guide each drill.

Once the drill strings met approximately in the middle of the 6,131-foot drill, the Sapling Point Drill string was backed out with the Florida Avenue drill string following in the bore hole created by the Sapling Point directional drill until both drill bits exited at Sapling Point as seen on page 4. The pilot hole was surveyed upon completion and it confirmed that not only did the route match our design, but also that the actual length was

Florida Avenue Substation
Directional Drill Rig
1,100,000 Pound Pullback Capacity

Sapling Point
Directional Drill Rig
625,000 Pound Pullback Capacity

Sapling Point Artificial Magnetic Field Path Used for Drill Bit Steering

only 2-feet longer at 6,131-feet than our 6,129-foot length indicated in the design. With the route confirmed to match the design drawings, the Sapling Point directional drill rig was no longer needed and therefore removed to make room for enlarging the pilot hole to the 48 inch diameter required to pull back the 36-inch steel casing. Throughout the drilling operation, a mixture of water and naturally occurring Bentonite Clay, known as "drilling mud" was used. This drilling mud maintained the integrity of the borehole, provided lubrication for the drill string and also provided a fluid flow for removal of cuttings. The drilling mud weighed approximately 9.5 pounds per gallon compared to Wolf Bay water which weighed approximately 8 pounds per gallon. The higher drilling mud density compared with water created a constant outward pressure throughout the length of the tunnel and prevented the weight of Wolf Bay and soil overburden from collapsing the tunnel. Once the pilot-hole was complete, drill pipe was maintained through the entire length of the borehole until it was used to pullback the 36-inch steel casing.

The bore was increased in diameter from a rough 8-inch diameter pilot-hole, to 48 inches using two separate reamer passes, pulled back one at a time with the drill string in the borehole. Drill pipe had to be added to the Sapling Point site and removed from the Florida Avenue Substation site as the ream progressed to maintain a complete length of drill pipe in the borehole until each reamer exited at the drilling rig. This process required trucking drill pipe from Florida Avenue where it was removed and adding same to the Sapling Point site throughout the reaming process.

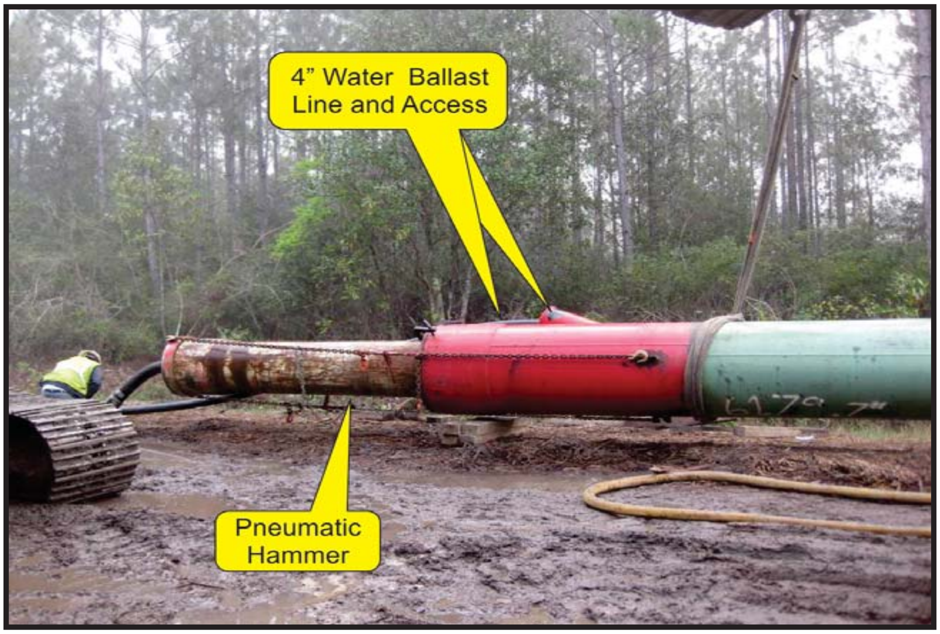
Sapling Point Exit of Both Drill Bits

The initial ream was 36 inches in diameter followed by a 48 inch ream with a separate swab pass immediately before the casing pullback. A swab is a short piece of pipe with mud jets and cutting teeth located on each end and used to not only center the reamer in the hole, but also to remove cuttings and debris with each pass.

36-Inch Steel Casing Installation

During initial pullback of the 36-inch steel casing, pulling forces greatly exceeded predicted levels causing the backstring to exceed the pullback capability of the equipment and get stuck with only about 1,000-feet of pipe in the hole. This required removal of the backstring, using multiple backhoes to slowly extract the pipe and not only save the backstring but also save the drilled hole. It was at this point in the project that the insurance provided by adding the 36-inch steel casing to the duct system design paid huge dividends in both time and money. If an HDPE or PVC bundle installation had been attempted without the steel casing, much of the backstring as well as the drilled hole would have been lost.

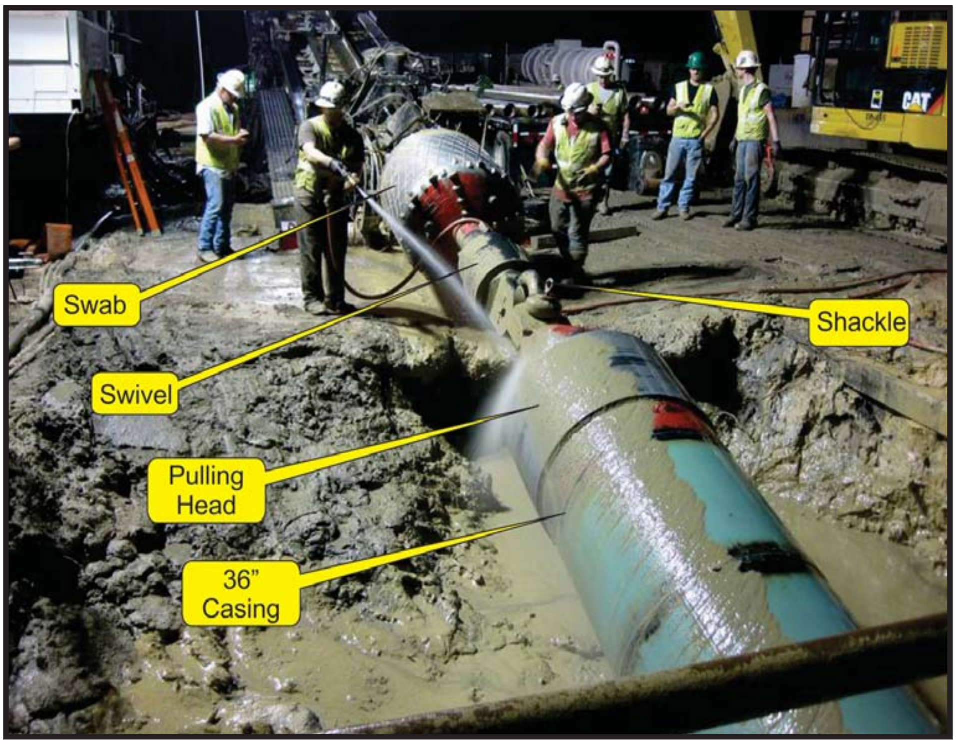
After the backstring was stuck and removed, the borehole was again reamed and swabbed in preparation for a second backstring pullback attempt. The first failed attempt made it obvious this was going to be a difficult operation, and although 20-hours of continuous pullback was originally estimated for pullback, it took approximately 68-hours to complete the crossing. It appears the geological formation allowed the drill string to sink below the bottom of the bore and become "key-seated" in the bottom of the borehole.



Pneumatic Hammer Located At North End of Backstring

Note: 4-inch Ballast Line entered at end of backstring with discharge near pulling head to control pipe buoyancy during pullback under Wolf Bay

This created a major challenge in keeping the swab at the front of the pulling assembly rotating freely as required for the pullback. To address these unique soils conditions and successfully install the backstring, Southeast Directional Drilling (SED) delayed pumping ballast water in the 36-inch steel casing during initial stages of the pullback. The thought was that the additional buoyant forces created by the delay in ballasting would prevent the backstring from sinking in the bore and assist reamer/swab rotation. SED also used a pneumatic hammer located at the north end of the steel backstring to assist in breaking the frictional forces between the backstring and borehole throughout the pullback. At times the pneumatic hammer only caused the backstring to move a fraction of an inch with each hammer strike.



36-inch Steel Casing Exit Just South of Florida Avenue Substation

HDPE Backstring Installation

After 68-hours of continuous pulling from the Florida Avenue drilling rig and pushing from the pneumatic hammer located on Sapling Point, the 36-inch steel casing successfully emerged at Florida Avenue. The next step was to "pig" the steel casing in preparation to pull the HDPE bundle. This process not only proved the integrity of the steel casing and removed any debris that may have entered the pipe, it also left the casing filled with clean water, facilitating installation of the HDPE bundle.

The HDPE bundle would have been impossible to install without the steel casing as proved by the initial failed attempt of the steel casing. However, with the steel casing filled with clean water and the HDPE bundle flooded with clean water as it entered the casing, the bundle became essentially neutrally buoyant, which made the HDPE bundle installation extremely easy.

36" Steel Casing Pig

Water was used to push pig through 36" steel casing.

Thermal Grout

Following successful installation of the HDPE bundle, it was time to prove the integrity of each HDPE pipe with a gauging pig before installing the thermal grout. Once this integrity was proven, thermal grout was pumped between the HDPE bundle and the steel casing. Thermal grout is a combination of heat transfer minerals, water, additives, and cement all designed to stay in suspension during and after placement to not only maintain the integrity of the original mix design, but also provide uniform heat transfer properties. The advantage of using thermal grout is that if properly designed and placed throughout

HDPE Bundle Pulling Head

Note: Pulling head allowed water from 36-inch casing to enter HDPE bundle upon pullback allowing bundle to be neutrally buoyant and minimize frictional forces during installation.

the entire length of the installation, the improved heat transfer properties can more efficiently remove heat generated by the electrical cables during operation and effectively increase cable ampacity ratings.

Our concern with relying on thermal grout for this design was due to the extreme 6,131 foot length of the Wolf Bay Crossing. The previous world's record for thermal grout installed in a duct system that we could find was set at 3,500 feet. Unfortunately, this length was just over half the length required for the Wolf Bay crossing. If we relied on the increased ampacity provided by the thermal grout and for any reason we couldn't displace all the water between the HDPE pipes and steel casing with thermal grout, the cable would be undersized and unable to carry the required 300MVA load. Therefore a conservative engineering decision was made to rely on the thermal conductivity of water that may remain in the pipe, which is less than the thermal conductivity of the grout. If a thermal grout installation could be achieved, the cable capacity could be increased above the 300MVA required, but at least 300MVA would be ensured if complete grout placement didn't work.

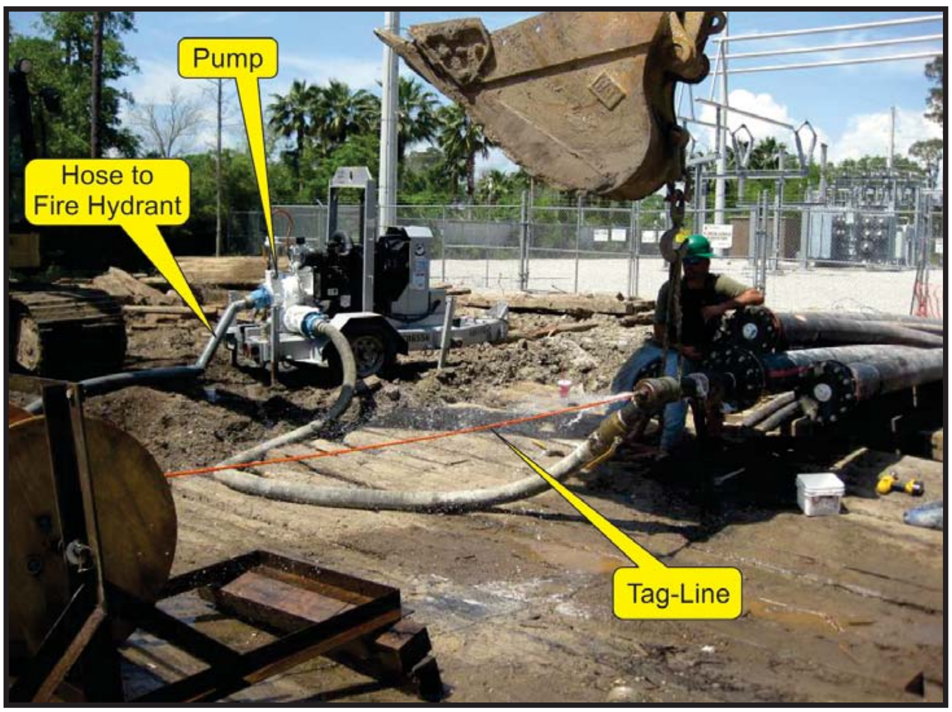
The design also required that the grout mixture minimize heat build-up during curing to prevent damaging the HDPE pipe as well as physically cement the HDPE bundle inside the steel casing. The Constellation Group LLC provided a ther-

Gauging Pig

Aluminum disk on gauging pig ensures HDPE pipe internal diameter throughout the entire installed length is adequate for cable installa-tion.

mal grout design and construction support during installation that met these require-ments. Since grout pumping distances were in excess of one-half mile, the ther-mal grout had to be extremely fluid while maintaining the thermal characteristics specified. The final design provided grout with a consistency of latex paint, but it weighed 118 pounds per cubic foot.

Five 4-inch diameter sacrificial grout pipes called "tremie lines" were installed from each end of the steel casing and strapped to the HDPE bundle. This design provided a total of ten sacrificial pipes with outlet locations spaced throughout the duct length to help ensure grout placement throughout the entire length. The space between the HDPE bundle and the steel casing was calculated at 662.2 cubic-yards. With 657 cubic-yards of grout pumped, 99.2 percent of the total volume available between the HDPE bundle and the steel casing was filled with grout. This success almost doubled the previous world's record for grout fill in a duct system and set a



HDPE Pigging and Tag-line Installation

Water from fire hydrant to pump used to push gauging pig through duct with tag-line attached to pig providing method to pull winch cable required for cable installation.

Thermal Grout Installation

new bar for increasing cable ampacity by incorporating thermal grout in exceptionally long duct systems.

After successful installation of the thermal grout, a second gauging pig pass was made to prove the integrity of each HDPE pipe. A 3/8th inch diameter rope was tied to the final pig run in each pipe providing a tag line that would pull the cable eventually used to install each 115kV conductor.

Termination Structures

Termination structures were designed to allow the transition from underground cable to overhead line at Sapling Point and from underground cable to 4-inch aluminum bus at Florida Avenue required to tie into the existing substation.

Termination structure design at a minimum required considering:

- Cable installation and provisions for cable replacement
- Cable thermal cycling and a 40 year design life
- Cable snaking within the duct
- Cable metallic sheath strain
- A 6.7-foot minimum cable bending radius
- Cable and termination physical protection (e.g. Hurricane events)
- Cable termination
- Transition from underground cable to overhead conductor

Provisions for cable installation and replacement if ever necessary were provided by a modular upper deck design along with removable concrete panels located on the opposite wall from the cable entry as seen in the photo below.

Part 3 - 115kV Cable Design, Selection and Installation will appear in the 3rd Quarter Edition of The Consultant

Florida Avenue Substation Termination Structure

Removable panels installed after successful cable installation and racking

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