



# **Progress Energy Southport Nuclear Power Plant Diversion Structure Stabilization Project**

**Submittal for the**



**Pile Driving Contractors Association (PDCA)**

**2010 Project of the Year**

**Submitted by: Taylor Bros. Marine Construction, Inc.**



## PROJECT OVERVIEW

The Progress Energy Nuclear Power Plant is located in Southport, NC and consists of two General Electric Boiling Water nuclear reactor generating stations. Due to its unique location near the Cape Fear River and the Atlantic Ocean, the plant draws its cooling water in from the Cape Fear River where it flows approximately 2 miles down a man-made canal. Once the water is used as coolant for the steam turbine condensers, it is discharged from the plant to the Atlantic Ocean via a 5.5-mile man-made canal, passing through a massive tunnel underneath the Intracoastal Waterway (Figure 1). As seen in this satellite photograph, the plant is massive, and is a significant engineering and construction achievement.



**Figure 1.** Progress Energy Nuclear Power Plant Coolant Flow Canals



To prevent marine life such as fish and turtles, along with marine sea grass from entering the plant, a large Diversion Structure was built at the inlet of the Intake Canal. This 30-year old structure is V-shaped, with the annex facing the Cape Fear River at the center of the structure (Figure 2).



**Figure 2.** The Diversion Structure

It consists of 2 end pile bents and 13 interior bents. Each bent is made up of four 24-inch square concrete piles with an imbedded H-Pile stinger in the end for driving. The tips of the piles are located at approximately -40 feet mean sea level with pile the stingers protruding an additional 10 feet into the bottom. A wire mesh screen and turtle excluder is maintained between each bent, and can be raised for cleaning by each of two special cleaning rigs on each leg of the structure (Figure 3).







**Figure 3.** Diversion Screen and Turtle Excluder

The screens rest on a seat beam affixed to the top of sheet pile extending to the bottom approximately 20 feet down from the surface of the water. With both reactor plants online drawing cooling water, and depending on the tidal level, there can be up to 3 feet of differential head on each of the screens. This differential pressure (DP) is felt for the entire vertical length of each screen, resulting in very large forces applied to the structure during high DP conditions. Of note, hurricanes and tropical storms can produce unusually high tides, which further increase the DP imposed on the structure. As a result of recent storms last decade, two of the structure bents have moved inward (away from the Cape Fear River) with a maximum deflection of 9-3/4". If left uncorrected, this condition would further worsen, forcing the plant to be shutdown pending repairs.

Progress Energy contracted a well-known and reputable engineering firm to design a corrective system of driven piles to shore up the structure and prevent further movement. Taylor Bros. Marine Construction, Inc. (TBM) was contracted by Progress Energy to drive two test piles, and perform the subsequent installation of the driven pile system.

This project showcases that driven piles can be installed in the toughest of marine environments, and are often times the only viable solution to a problem encountered in the marine environment. It further illustrates that pile driving and foundation drilling often go hand in hand when soil conditions dictate, and that project owners and contractors should consider contingency plans for





this necessity prior to generating contract documents, rather than after a problem has been encountered. It also illustrates the necessity to perform an adequate number of pre-job borings regardless of the apparent extra costs. The initial impending failure of the structure (movement) illustrates the need to ensure that the driven pile is installed per the minimum driving criteria to achieve success.

## MEETING THE CHALLENGE OF A DIFFICULT JOB

**Coordination and Efficiency:** The most significant known challenge at project start was the required coordination between the pile driving crew and the diversion structure maintenance crew. The mesh screens must be cleaned daily (sometimes more often) due to heavy build up of sea grass and river debris. Each of the two legs of the structure has a rail-mounted cleaning machine that lifts the screens, then diverts the debris to a collection chute as it is manually removed (Figure 4). Since all of the driven piles were in close proximity to the structure, and the batter piles actually pass over the structure before driving to grade, very close coordination was required to prevent shutting down the structure. If the structure became “clogged” and prevented sufficient cooling water intake, one reactor plant would be shutdown until the problem could be corrected. If the structure became further fouled, the second reactor plant would be forced to shutdown as well. The delay charges for shutting down each reactor plant approach approximately \$ 1 Million per day, per plant.



**Figure 4.** Rail-mounted Cleaning Machine



To mitigate the risk of shutting down a plant, which would completely eliminate all profit and fun for the job in an hour or so, a very efficient pile driving system was needed. Once started, a pile had to be set and driven below the grade of the structure rail for the cleaning machines before the machine had to pass by that location. TBM designed and built a template that could be used for the vertical piles, and then rotated for the batter piles. It was bolted to the pile caps using the studs that were installed for the future pile connections to the structure (Figure 5). This enabled TBM to drive a vertical and batter pile at each bent with one template, with minimal setup between piles.



**Figure 5.** Template Utilizing Connection Studs

**Anticipated Hard Driving:** In addition to the necessity to set and drive piles in less than a day once a pile was set to prevent cleaning machine interruption, the driving conditions were expected to be very tough. The boring report revealed a layer of Limestone and Cemented Sands at -45 to -50 feet that was 2 feet thick at one end of the structure, and greater than 5 feet thick (boring terminated) at the opposite end. Of note, only four borings were performed. All were near the apex of the structure, and all were **outside** of the structure. This soil profile is typical of the Cape Fear region, and TBM has experience driving pile in these soils. TBM has been able to successfully “spud” through cemented sands on other projects nearby. Spudding consists of driving a heavier member through the layer with a diesel impact hammer to break up and loosen the hard layer. The spud is then extracted, and the job pile driven through the hole. TBM conducted the test pile program approximately one year previous by driving two HP 14 X 89# piles near the apex and outside of the structure. These piles drove easily. However, faced with the consequences of interfering with cleaning machine operations, TBM mobilized with all necessary equipment to spud piles as efficiently and quickly as possible.



**Remote Location:** Also a significant known challenge at the start was material delivery to the job site. A convenient boat ramp was located inside of the structure in the coolant intake channel, but no barges or tug boats could access it because the structure blocks access from the outside. All heavy material (piling, templates, etc...) had to be transported via barge from a loading area approximately 2.5 miles away in a creek that could only be traversed by TBM's shallow draft tug during periods of high tide. The next closest viable loading yard was approximately 18 miles up the Cape Fear River.

## UNIQUE APPLICATION OF PILE DESIGN

The pile system installed consisted of fifteen 14 X 89# H-Piles on the outside of the structure, battered 3 to 1. These piles were connected to each bent by a pre-fabricated stainless steel plate and pin assembly, which transferred the lateral forces of the structure to the pile, which was in tension. Since the outside piles were in tension, tip elevation was critical in developing pile pull out strength, and therefore penetrating the Limestone and Cemented Sands layer was necessary. On the inside of the structure, nine 20" diameter, 0.500" wall pipe piles were driven vertically adjacent to nine existing pile bents. 16" diameter, 0.500" wall pipe piles were driven at a 3 to 1 batter adjacent to the 20" piles and welded to the vertical piles near the top of the structure to form an A-frame type brace (Figure 6).



**Figure 6.** A-Frame Assembly





A collar and plate assembly tied each A-frame assembly to its associated existing pile bent. The A-frames were also tied together by welding in a 10" diameter, 0.500" wall pipe pile horizontally just below the elevation of the existing structure deck (Figure 7).



**Figure 7.** 10" Pipe Horizontal Brace

The inside piles were under a compressive load, and were also required to absorb lateral movement, so they also were required to penetrate the limestone and cemented sands layer. All piles were equipped with field-welded cutting shoes to improve tip performance during tough driving conditions.

The impact hammer used to drive the piles was a TBM owned APE D32 single acting diesel impact hammer capable of developing 74,750 ft-lbs of energy. Pile driving criteria was developed during the test pile program and during job pile driving by conducting Pile Driving Analyzer (PDA) monitoring on select piles.

## CONSTRUCTION PROBLEMS AND SOLUTIONS

**Unpredicted Driving Conditions:** Once driving criterion was developed, driving commenced from a barge-mounted crane using the single-acting diesel hammer. The first eight outside tension piles were driven easily with the bolt on template. The HP14X89# piles were driven at a 3 to 1 batter and varied in length from 75 to 85 feet. However, the ninth pile did not drive



nearly as easily, but finally ‘punched’ through a 3 ft. layer with no damage. The tenth pile was driven to refusal after the tip reached the elevation of the limestone. TBM suspected pile damage based on its prior experience with damaged H-Pile at refusal, and extracted the pile with a vibratory hammer. The pile showed extensive buckling and was repaired (Figure 8).



**Figure 8.** Damaged H-Pile

Several attempts at ‘spudding’ with various reinforced piling were conducted with each attempt resulting in a damaged spud. After several attempts, it was concluded that the thicker limestone was too thick and dense to penetrate via spudding. It was later determined that the limestone varied in thickness from 7 feet to 13 feet throughout the remaining area requiring piles.

When the hard limestone was originally encountered, TBM initiated an exploratory program by driving an H-Pile with a vibratory hammer to determine if limestone was present at the inside pipe pile locations. Contact with the limestone is unmistakable when using the vibratory hammer and steel pile. Of note, no soil borings had been performed inside of the structure, presumably due to the difficulty of mobilizing a floating bore driller inside of the structure (Figure 9). There were a total of four outside battered H-Piles remaining and nine inside 20” diameter vertical pipe piles coupled with eleven 16” diameter battered pipe piles. Unbelievably, the limestone and cemented sand layer was present at ALL inside pile locations. This meant that of the thirty-five piling locations, limestone and cemented sands were present at all but eleven pile sites (70%).



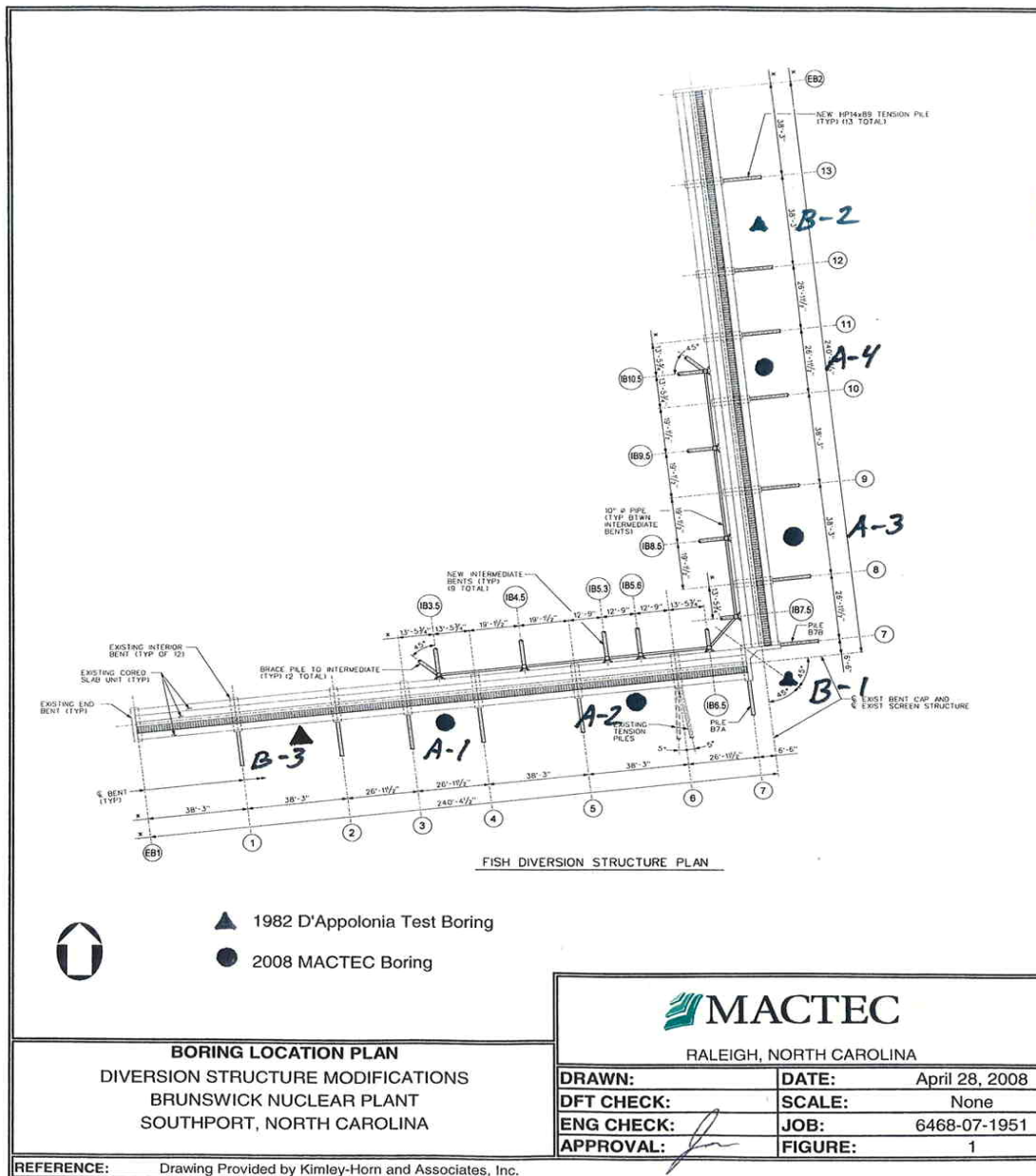


Figure 9. Boring Location Plan





***Drilling in a Uniquely Challenging Environment:*** After discussion with the engineer and owner, it was decided that drilling through the limestone and cemented sand layers would be the most effective and only viable method of solving with this problem. Spudding through with a much larger spud was a possibility, but would require much larger and more expensive pile driving equipment, with no guarantee of success since no inside borings were done to determine the layer thicknesses or hardness. This option was high risk with a low probability of success.

Three types of drilling were evaluated as feasible for this project. A down the hole hammer drill, core drill, and auger drill were compared. The down the hole hammer would create a significant silt generation and environmental permitting problem. Additionally, since the limestone and cemented sands were a layer and not continuous rock, the possibility of losing a down the hole hammer after it penetrated the layer was significant. Therefore, it was decided to use a conventional drill machine to drill, with both core and auger bits mobilized with it. A drill with a diameter of 36" was chosen so that the 20" diameter pipe piling would have sufficient clearance locate the drilled hole. A 45' long, 42" diameter, 0.375" wall pipe was used as a drill casing to precisely control the hole location and control silt generated from the drilling operation. Once drilling commenced, it quickly became apparent that the auger was much faster than the core drill, therefore the bulk of the drilling was done with auger bits.

Although seemingly simple at first glance, drilling a hole for the batter piles was not a trivial task. First, drilling a 3 to 1 battered hole into a layer 42 to 43 feet down, and then subsequently finding that hole with the job pile was a difficult if not impossible task. Secondly, the range of tide at the structure was approximately 5 feet, which would make drilling the battered hole nearly impossible from a floating barge due to the constantly changing angle of the drill shaft. Mounting the drill machine on the structure was evaluated, but that would prevent operation of the cleaning machines, which was not desired. Therefore, TBM developed a "slot" method of drilling by drilling overlapping, vertical holes in the direction of batter. The number of vertical holes (length of slot) was determined by the thickness of the layer at that pile site, which was directly observed by drilling the vertical pile hole first. AutoCAD was used to draw each batter slot location with the layer thickness to scale to determine how many vertical holes were needed to complete the slot.

***Mobilizing a Large, Floating Platform Inside of the Structure:*** Mobilizing a floating, truck-mounted drill rig inside of the structure with no way to move a barge inside of the structure was a problem with only one viable solution. Shugart pin-together barges were used to create a 30' x 100' spud barge with a slot located in one end by staggering the pin-together sections by one half a section width (5'). The drill rig straddled this slot so that the holes for the 20" vertical piles and the slots for the 16" batter piles could be drilled without moving the barge (Figure 10). The barge was spudded in place by manipulating the spuds with a crane barge located outside of the



structure. This arrangement ensured that the holes would be lined up perpendicularly to the structure and in the direction of batter. A template for the casing pipe was made that fit inside of the slot and could be easily slid up and down the slot and pinned in place to precisely locate the hole.



**Figure 10.** Drill Rig on Shugart Barges with Slot

The sections of the barge were arranged following the completion of stability calculations to optimize the section layout and minimize barge list and trim. The 28,000 lbs. barge sections were launched at the remote loading site, transported to the structure via the 2.5-mile creek, lifted over the structure and assembled. Once assembled, the barge was moved to the boat ramp inside of the structure, and the drill rig loaded onto it. Once drilling of the holes and slots inside of the structure were complete, the drill rig was off-loaded at the inside boat ramp, driven to the remote loading site, and loaded onto a TBM 30' X 80' spud barge. The barge was transported back to the site via the 2.5-mile creek, and positioned for the outside drilling.

***Precisely Locating Holes to be Drilled:*** The holes would be of no use if they could not be precisely located, drilled, and then located again following removal of the drill rig for job pile placement. In order to precisely locate the hole, and to control drill-generated release, a casing was used (Figure 11).





**Figure 11.** Casing Located in Barge Slot

Fortunately, the elevation of the top of the limestone layer was very consistent, while the bottom (under side of the layer) elevation varied. This facilitated the use of a single length casing pipe. A 42" diameter, 45' long steel casing was driven with a vibratory hammer supported by the outside crane barge, through the silt layer, resting on top of the limestone and cemented sands layer. The drill rig then removed the silt in the casing so that the weight of the silt did not bear on the drill auger, or flow into the cooling water intake. Once the silt was removed from inside the casing, the actual drilling through the limestone commenced. The extreme hardness of the limestone yielded drilling times of 1 to 4 days to completely penetrate the layer. According to the experienced drill team, this material toughness was on par with granite. Before moving the barge and drill rig to follow-on holes, accurate measurements of the hole location were documented to aide in subsequent job pile placement. Once the drill rig was set up on the next hole, the bolt-on template was installed. The template guided each job pile precisely into the hole for the vertical piles, and the slot for the battered piles. Finding the drilled holes, especially the slots, without this precise system of controlling the casing and guiding with the bolt-on template, would have been extremely time consuming if not impossible.

After all piles were driven, they were fitted and welded to plates bolted to the concrete diversion structure caps using the previously installed studs. The welding work was complicated by the fact that it was over the water and the 16" batter pipe piles had to be fitted and welded precisely to the 20" vertical pipe piles (Figure 12). Once TBM's portion was complete, the owner's contracted divers performed the below water connections from the new pile to the structure.







**Figure 12.** Pile Connections to Structure

## **INNOVATION IN CONSTRUCTION TECHNIQUE**

The most innovative accomplishment of the project was the development of the slot drilling method for the batter piles. Again, this allowed the batter piles to penetrate the hard layer without the need to drill a hole at the batter angle, which would have been extremely difficult from a floating platform with varying tides, and would have shut down the structure if done by mounting a drill on the structure. This also prevented the drill rig from tilting its mast out over water, which made the operation much safer by minimizing the chances of a tip over accident.

Also innovative was the bolt-on template utilizing the studs for the subsequent connection system. This created a precise guide for locating the job pile in the applicable hole or slot.

The use of the Shugart pin together barges was innovative, which enabled TBM to mobilize a large barge on the inside of the diversion structure which has no water-borne access.

## **COST SAVING MEASURES**

Although difficult to save money when a serious problem such as this occurs, several things were planned by TBM prior to the job, and several actions were taken post problem to mitigate costs.



**Pre-Construction Planned Cost Saving Measures.** As stated previously, shutting down each power plant for any reason would incur costs approaching \$1 million per day per plant. To preclude this, a system of efficiently driving the piles without interfering with the structure cleaning machines had to be developed. As detailed in “Meeting the Challenges of a Difficult Job,” the bolt-on template method was designed, fabricated, and worked extremely well.

Additionally, a contract clause illustrating the possible necessity to drill in the event of failure of the spud method was added at the request of TBM prior to contract execution. This minimized considerable delay in the subsequent modification of contract documents to proceed once it was determined that conventional pile-driving methods were not possible.

Also, significant time was saved in fitting the batter pile to vertical pile welds. Steel Fabrication Software, a pipe fitting software application, was used to layout the batter pile to vertical pile cuts for fit up and welding. The angle between each pile was measured using an electronic level, and this was entered into the software along with each pipe diameter. The software generated a table providing plot points along the diameter of the pipe to be cut. These points were manually plotted on a flexible sheet of linoleum. The linoleum was trimmed per the plot, wrapped around the batter pile, and marked. The mark was cut via hand torch, and fitted to the vertical pile. Very little if any trimming was required prior to welding. This application proved to be extremely precise and saved a significant amount of time in cutting and fitting the pipe together.

**Additional Cost Saving Measures:** Once the problem of extremely difficult soils was encountered, TBM immediately proceeded with a probing program to determine the extent of the problem. This was done at no additional cost to the owner, and its results allowed the owner and engineer to make informed decisions sooner, thus saving money for all.

Also, the drilling method selected and tailored for this situation allowed both reactor plants to remain in operation while the problem was solved, saving many millions of dollars in lost revenue for the owner. The drilling operation would have been significantly faster and cheaper for TBM if done by mounting the drill on the structure. This would have permitted one hole to be drilled for the batter piles vice the several holes to make up the slot. This would have likely limited plant operations, as at least half of the structure would have fouled due to the inability to clean it during drilling. However, TBM opted to use the floating drill rig method, which maintained the structure fully operable at all times during the project. Also, no environmental permitting delays were encountered because of the selected method of drilling. Since the casing contained all drilling silt and residue generated, no additional permits were required.

TBM also mobilized another complete crane barge pile-driving rig and tug boat during the drilling phase to permit pile driving at the drilled sites, while simultaneously supporting the drill rig with the original crane barge. Once a vertical hole and battered slot was complete, the first



crane barge would move the drill rig to the next site and set the casing in place to start drilling (Figure 13). While the casing was being set, the second pile-driving rig would set up and drive the job piles. This saved time by simultaneously drilling and driving job piles to the maximum extent possible. TBM charged no additional mobilization or operating costs to the owner for this equipment.



**Figure 13.** Crane Barge Supporting Drill Rig

Additionally, TBM kept the drill rig mobilized on site until all piles were driven. This time was minimal since pile driving was performed in conjunction with drilling, but necessary in the event of a failure to locate a drilled hole or slot with a job pile. This never occurred, but the drill rig was on site and ready if it had, and no re-mobilization costs would have been incurred.

TBM's solution to this problem also prevented the replacement of multiple sections of the diversion structure, which would have shut down both plants, and cost magnitudes more. Although seemingly expensive at first glance, the floating drill rig method saved a significant





amount of money by maintaining both plants operable at all times. The power plant was never shutdown or limited in any way by the diversion structure project.

## **MITIGATION OF ENVIRONMENTAL CONSIDERATIONS**

The most significant environmental issue faced during the project was choosing the method of drilling. Drilling can create large amounts of silt and turbidity, which is unhealthy and even fatal for some marine life. Excessive silt would have also fouled the plants' steam turbine condensers. This hazard was minimized if not eliminated by choosing the auger method of drilling inside of a casing.

## **LESSONS LEARNED**

TBM learned many lessons during this project. Some are obvious while some are not. Most notably, pre-job borings are vital to the success of any project. Adequate borings should be performed covering all areas where piles are to be driven. No assumptions should be made based on borings taken "around" the driving site, and every effort should be made to bore in all areas where piles will be driven. As illustrated by this project, driving conditions can change rapidly over a short geographical distance.

Also a lesson "re-learned" by all involved, is that driven piles perform well when, and only when, they have been driven to meet the minimum driving criteria. Although unable to positively confirm, TBM suspects that the original job pile stingers in the structure were not driven through the hard layer of limestone and cemented sands, which resulted in the observed shifting of the structure. The H-Pile stingers on the ends of the piles were likely damaged by the harder than expected limestone layer, as were the several spuds driven by TBM. This also highlights the necessity of performing an adequate number of PDA tests on driven piles to determine the status of damage to piles as they are driven.

Overall, this project was very successful due to the efforts of TBM and the project owner, Progress Energy. TBM worked hard to provide prompt solutions to the owner, even at significant cost to TBM. Likewise, the owner was very proactive and responsive to TBM during the decision making process, and enabled the project to proceed with minimal delay time awaiting engineering and corporate decisions. The end result is a nuclear power plant in operation with a fully functioning diversion structure to protect the plant from fouling, and marine wild life from the coolant stream. As always, A Driven Pile is a Tested Pile!

