The Morris Island Lighthouse
Phase I Foundation Stabilization Project

Submittal for
Pile Buck International, Inc.

Submitted by:

Taylor Bros. Marine Construction Inc.

&

WPC Inc.

Company Name: Taylor Bros. Marine Construction, Inc.

Member of PDCA Chapter: South Carolina

Chief Executive Officer: Julius Taylor, Jr., PE

Entry Submitted By: Julius Taylor, III (Taylor Bros. Marine) & Josh Adams (WPC Inc.)

Company Name: Taylor Bros. Marine Construction, Inc.

Address: Taylor Bros. Marine Construction, Inc.
135 Oak Road

City: Beaufort State: NC Zip: 28516

Web Page: www.taylorbrothersmarine.com

Phone: 252-728-2525 Mobile: 910-622-3770

Email: jmtayloriii@gmail.com, jadams@wpceng.com

Project Title: Morris Island Lighthouse Foundation Stabilization Phase I

Project Owner: U. S. Army Corps of Engineers

Project Start Date: April 20, 2007 Completion Date: March 28, 2008

PROJECT SUMMARY

The Morris Island Lighthouse is an iconic, historic structure in Charleston, SC. Since construction of the lighthouse was completed in 1876, it has endured ten (10) hurricanes of Class I or greater, the 1886 Charleston earthquake, and bombing at the end of nearby Folly Beach during World War II. However, construction of jetties at the entrance of Charleston Harbor to improve shipping access from 1878 to 1896 started the erosion of Morris Island. In the 1890's, the lighthouse was approximately 2,700 ft from the shoreline (Figure 1a). By 1938, the shoreline was at the lighthouse (Figure 1b) and the exposure of its foundation to the Atlantic Ocean began.

(a) circa 1876[1] (b) circa 1938[2] (c) 5/2007[3]

Figure 1. Selected Morris Island Lighthouse Photographs with Time.

The exposure of the lighthouse foundation to the ocean has led to the deterioration of the underlying timber piles and timber matting on which the structure is founded. A steel sheet pile cofferdam was installed around the lighthouse in 1939 to protect the lighthouse foundation. However, over the years, those sheet piles have corroded away above the mud line, once again exposing the lighthouse foundation. Over time, the timber piles under the lighthouse have become severely degraded, compromising the foundation integrity and moving the lighthouse towards collapse. In order to protect and stabilize the Morris Island Lighthouse from further damage, a steel sheet pile cofferdam was designed by the U.S. Army Corps of Engineers. This design consisted of ring of 46 ft long PZ-40 sheet piles with a diameter of 72 ft and a protective riprap barrier. The new PZ-40 sheeting was installed within 6 ft of the existing lighthouse foundation.

This project showcases the following: that driven piles can be installed in hazardous marine conditions safely and effectively; how collaboration between a pile driving contractor and an engineering firm dispelled the myth that installation of sheeting with vibratory hammers in sands damage adjacent structures; and that driven sheet piles are now effectively protecting a historic lighthouse in Charleston, SC.

---

1 Photograph courtesy of http://www.uscg.mil/hq/g-cp/history/WEBLIGHTHOUSES/LHSC.html.
2 Photograph courtesy of savethelight.org.
3 Figure taken by WPC personnel.

MEETING THE CHALLENGE OF A DIFFICULT JOB:
Currently, the lighthouse is approximately 1,600 ft from the shoreline (Figure 1c). Figure 2 presents the shorelines in 1854 and 1979 relative to the lighthouse in plan view. The exposure of the lighthouse foundation to the Atlantic Ocean had severely deteriorated the timber components (i.e. timber piles and timber matting) of the lighthouse foundation, as shown in Figure 3.

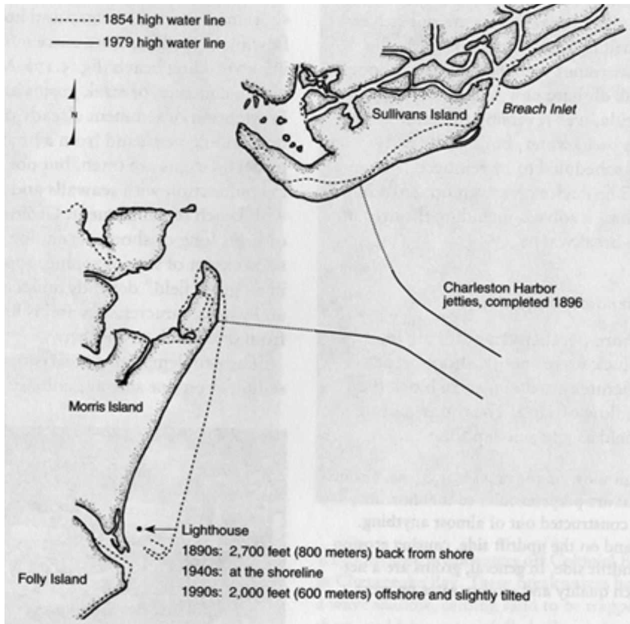

Figure 2. Morris Island Shorelines relative to Charleston Harbor Jetties
(Courtesy of http://www.wcu.edu/coastalhazards/Libros, after Zarillio et al., 1985).

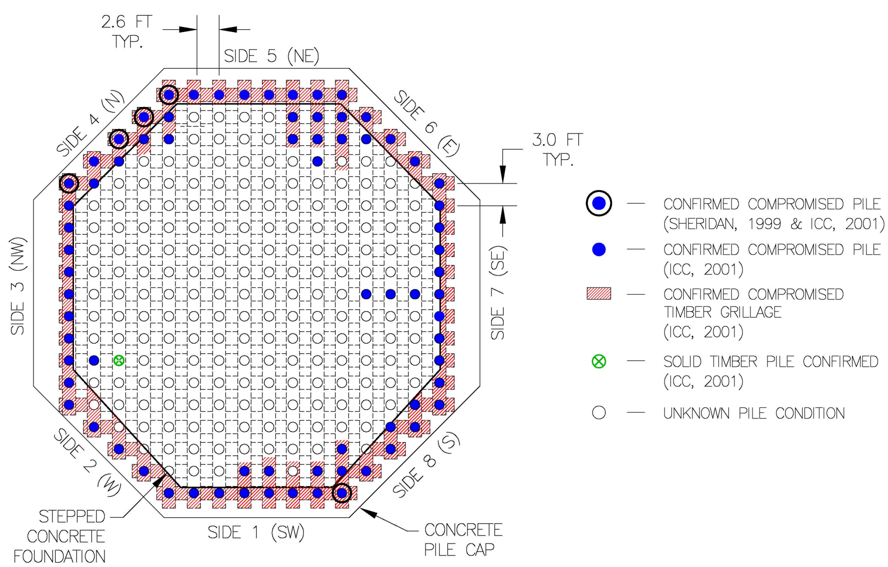

Figure 3. Composite Plan View of Confirmed Missing Timber Piles and Grillage
(After Sheridan, 1999; ICC, 2001; and Hajduk et al., 2007).

A total of 136 PZ-40 sheet piles by 46 ft long were installed to create the cofferdam. The steel sheeting required 16 mils (two coats) of coal tar epoxy polyamide on the top 15 feet of each sheet (i.e. to the mud line). Each sheet also had one each 24 pound zinc anode welded to it at the 15 foot paint interface line. The basic design concept is presented in Figure 4. The contract also called for the removal of the concrete debris from the 1939 repair, the installation of a geo-textile filter cloth below the riprap barrier, and the installation of six (6) 12-inch square pre-stressed concrete (PSC) piles to be used as the foundation of a new boat access dock.

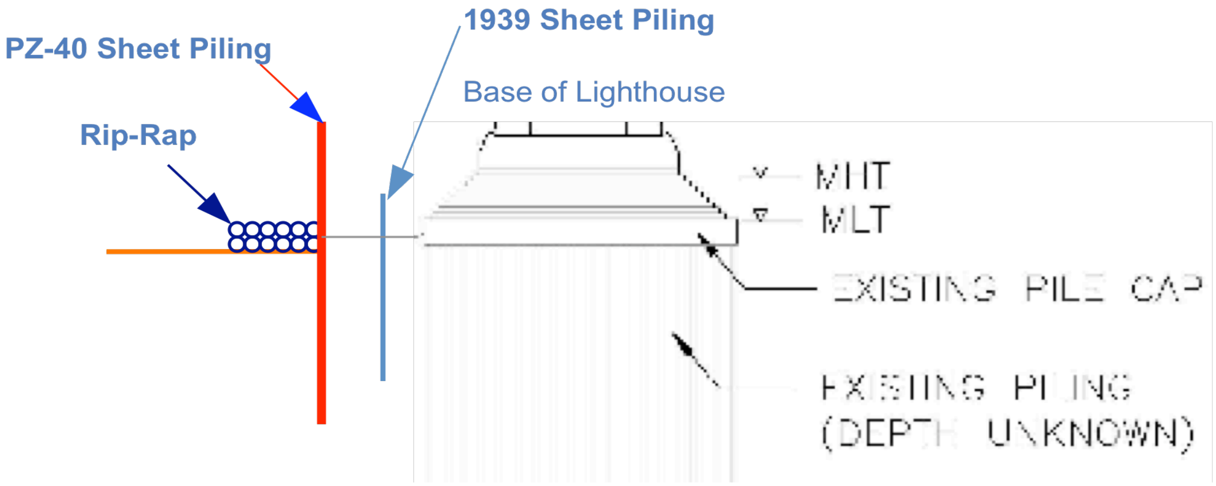

Figure 4. Morris Island Lighthouse New Sheet Pile Cofferdam Conceptual Design.

The following challenges surrounded the installation of the PZ-40 sheet piling around the historic structure:

- ***Access to the Lighthouse:*** Access to the lighthouse is difficult due to changes in tides, which average 6 ft difference between low and high tides, waves, wind conditions, and the deposition of sand bars around the lighthouse. Figure 5 shows typical wave conditions around the Morris Island Lighthouse.

Figure 5. Typical wave conditions at Morris Island Lighthouse.

A jack-up barge was selected for use to overcome the tide and wave challenges and provided a steady crane and work platform for the installation of the PZ-40 sheeting and associated HP piling for the template. The jack-up barge is presented relative to the lighthouse in Figure 6. Accessing the jack-up barge via small boat, and moving the jack-up barge still remained problematic during high sea days.

Figure 6. Jack-up Barge at Morris Island Lighthouse (taken from top of Lighthouse).

- ***Buried Obstacles:*** Remnants of the old lighthouse building foundations, walls, and portions of the 1939 repair were located around the structure. All of this debris was located below Mean Low Tide, with a substantial portion below the existing mud line. Figure 7 shows a foundation from the old light keepers residence visible at low tide.

Figure 7. Existing Debris around Lighthouse.

While some of the debris could be located at low tide, the exact location of the majority of these obstacles was unknown. The debris around the lighthouse prevented the installation of several PZ-40 sheet piles to the required embedment with the originally selected vibratory hammer (an APE Model 50). An extensive pile-probing program, consisting of driving and removing HP piles concentrically around the lighthouse, was implemented to determine the extent of the debris field around the lighthouse. The results of this pile-probing program are presented in Figure 8. After an extensive evaluation of different options, such as removal of the debris and expansion or contraction of the sheet pile cofferdam, the decision was made to increase the size of the vibratory hammer to an APE Model 150 and utilize a gravity drop hammer on stubborn piles and "punch" through the debris. This option was successfully implemented. The APE Model 150 performed very well, and the drop hammer was used on about 20 extra stubborn locations. Additional details of the various option evaluations are presented in the **Cost Saving Measures** section of this submittal.

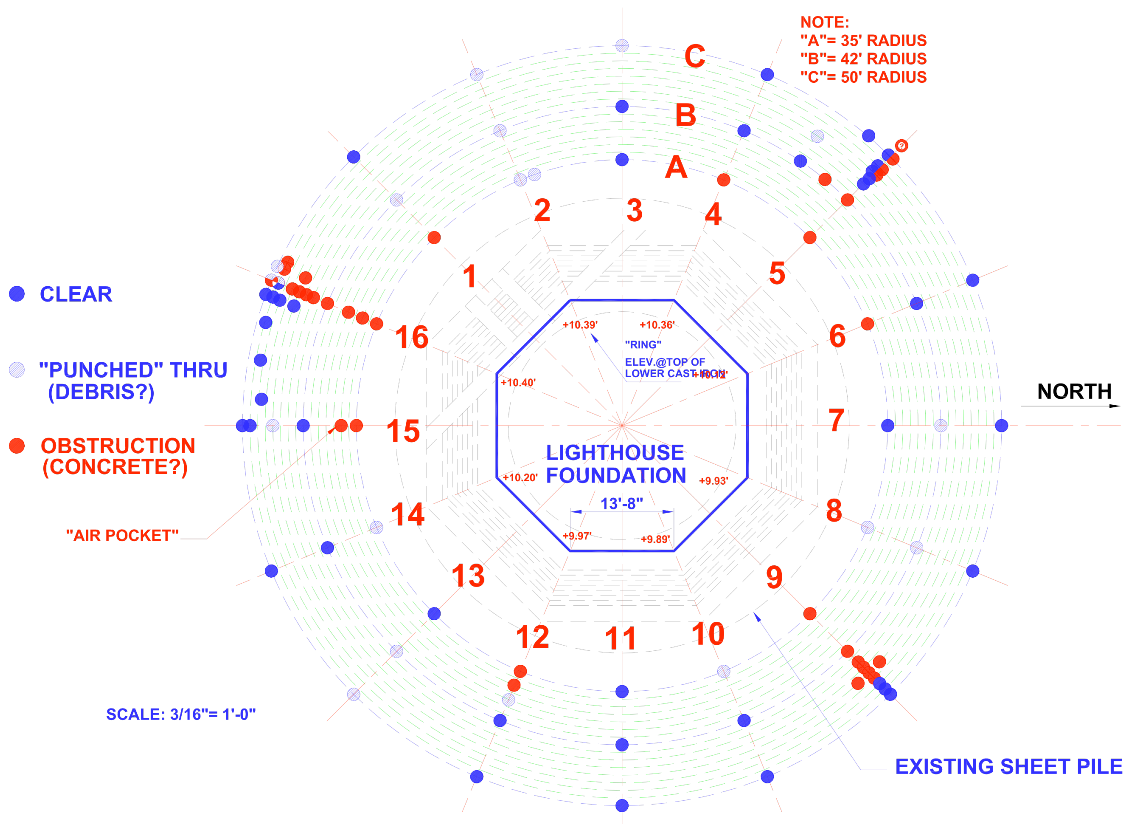

Figure 8. Pile Probing Program Results.

- ***Potential Damage to a Historic Structure:*** Given the proximity of the new sheeting to the historic lighthouse and the compromised nature of the existing lighthouse foundation, the possibility of the sheet pile cofferdam installation causing damage

was a major concern. Therefore, the specifications called for the development of a Vibration Control Plan (VCP) and pre & post condition surveys of the structure.
The pre-condition surveys of the structure showed that the structure had extensive cracking throughout and an existing rigid body lean. In addition, computer modeling of the lighthouse was conducted to determine its natural frequencies. A system of documenting and categorizing the existing cracks was developed and the existing lean measured. An example of the existing cracks is presented in Figure 9, while Figure 10 presents a compilation of lean measurements in plan view through the years.

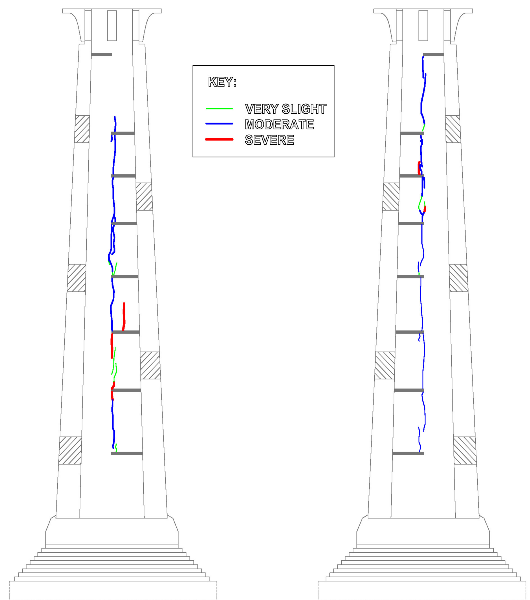

Figure 9. Documented Existing Interior Cracks for the Morris Island Lighthouse.

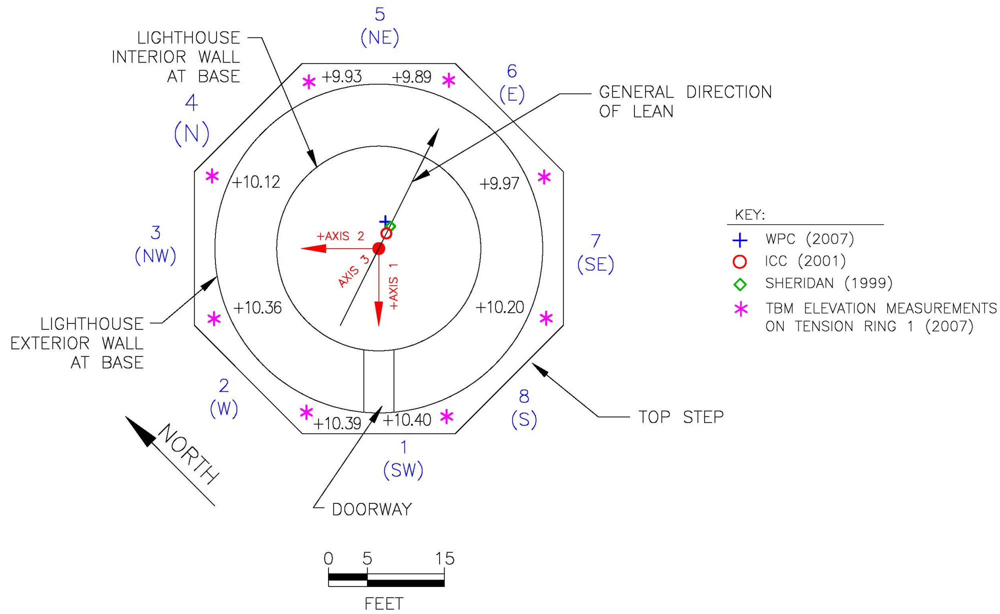

Figure 10. Existing Lean Measurements (Plan View).

Based on the pre-condition survey results, computer modeling, analysis of lighthouse existing documentation, and vibration analysis using data from the PDCA Driven Pile Ground Vibration Case History Database, an extensive instrumentation plan was developed that would monitor the lighthouse during all construction activities, to include driven pile installation. The instrumentation would measure structure tilt, existing crack movement, vibrations, and environmental factors such as temperature, wind speed and direction, etc. This monitoring data was placed on a website to be viewed by all interested parties. Figure 11 shows the data monitoring website.

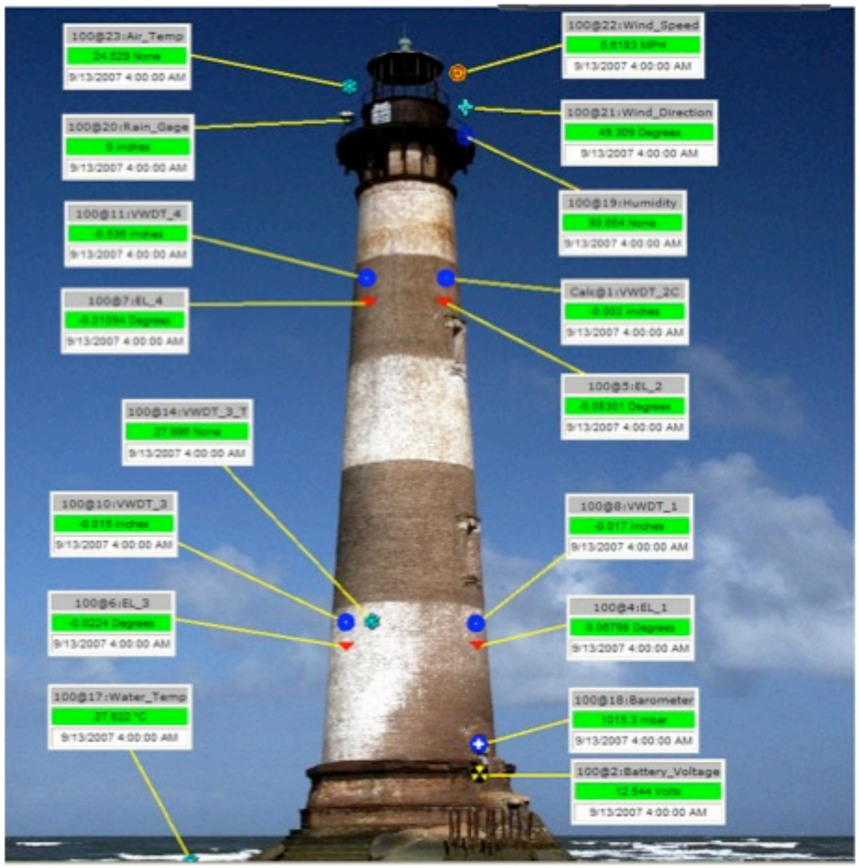

Figure 11. Morris Island Lighthouse Data Monitoring Website.

DESCRIPTION OF PILE TYPES AND UTILIZATION:
The following driven piles were used for this project:

- ***72ft Diameter Sheet Pile Cofferdam:*** PZ-40 by 46 ft long with 16 mils (two coats) of coal tar epoxy polyamide on the top 15 feet of each sheet (i.e. to the mud line).
- ***Template Piling:*** HP12x53 steel piles with lengths from 30 ft to 40 ft.
- ***Temporary Dock Piling:*** Two (2) 12 ¾ inch OD by 0.313 W.T. by 25 ft long Open Ended Pipe (OEP) Piles
- ***Permanent Dock Piling:*** Six (6) 12-inch square Pre-Stressed Concrete (PSC) piles x 46 ft long.

INNOVATION IN CONSTRUCTION TECHNIQUES OR MATERIAL:
This project involved upgrading a proven solution (i.e. cofferdams with steel sheet piling) with current corrosion protection techniques (sacrificial anodes, protective coating, and a rip-rap barrier with underlying geotextiles). The 1939 sheet pile repair is widely credited with saving the Morris Island Lighthouse. However, it was not designed to account for decades of corrosion and subsequently failed. The current cofferdam design accounts for this oversight and should protect the Morris Island Lighthouse for decades to come.

UNIQUE APPLICATION OF PILES OR DESIGN CONSIDERATIONS:

This project, which is essentially the installation of large sheet piling with a vibratory hammer in loose, poorly graded sands directly next to a historic structure with a compromised foundation, could be conceived by those without proper knowledge as the worse case application for driven piles. Critics against driven piles stated that this application of sheet piling installed with a vibratory hammer would generate vibrations that would settle the nearby sands and/or resonate the historic structure, causing irreparable damage. However, the use of engineering knowledge, specifically the data within the PDCA Driven Pile Case History Database, and an extensive monitoring program showed that vibrations generated from vibratory hammer driven sheet piling near historic structures can be managed. ***The monitoring plan showed that while the Lighthouse moved over the course of the project, these movements did not correlate to driven pile vibrations and that the completion of the sheet pile cofferdam stopped the lighthouse movement.*** In essences, the sheet pile cofferdam protection started working immediately.

CONSTRUCTION PROBLEMS AND SOLUTIONS:
As stated in the ***Meeting the Challenge of a Difficult Job*** section of this submittal, the project met with three major construction problems. The following is a summary of these problems and their solutions.

Access to the Lighthouse: Solved by the use of a jack-up barge.

Buried Obstacles: Solved by the use of a bigger vibratory hammer combined with a conventional drop hammer to “punch” through debris following debris mapping and a detailed analysis of various options. Additional details are provided in the in the **Cost Saving Measures** section of this submittal.

Potential Damage to a Historic Structure: Solved by conducting an exhaustive analysis of the structure and the effects of potential ground vibrations generated during the piling installations. The data from the PDCA Driven Pile Case History Database was used in this analysis. Figure 12 presents the predicted vibrations with distance for the APE Model 50 vibratory hammer. Also presented in Figure 12 are various vibration criteria, the distance from the new PZ-40 sheet piling to the old 1939 sheet piling, and the distance from the new PZ-40 sheet piling to the lighthouse foundation.

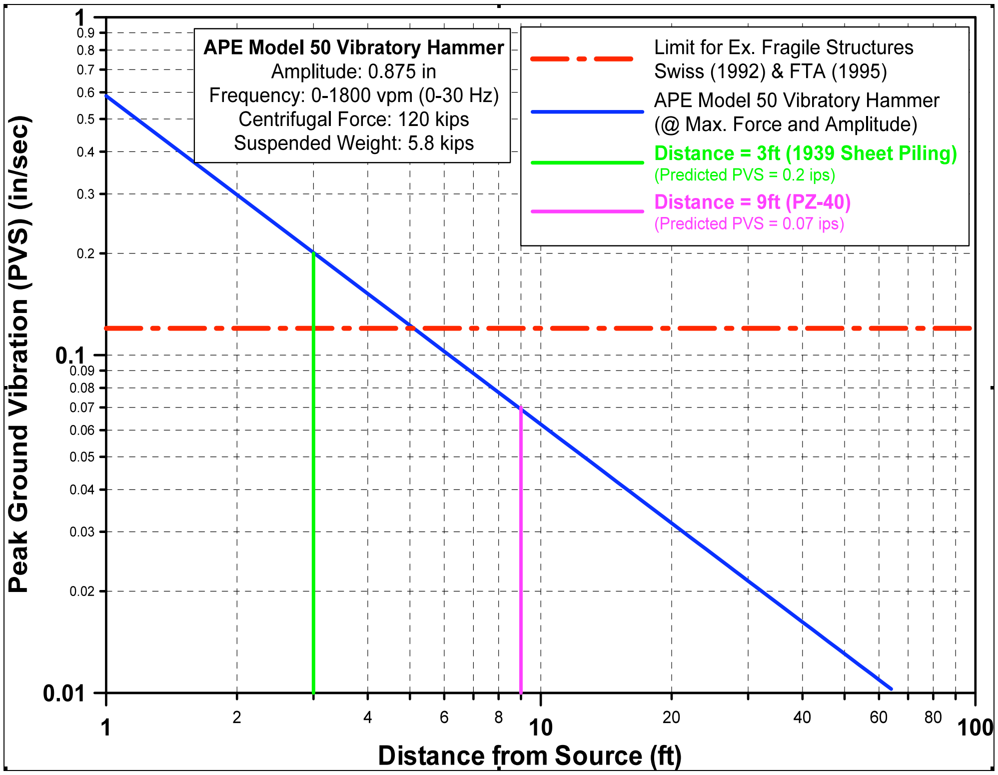

Figure 12. Predicted vibrations from APE Model 50 Vibratory Hammer (developed using PDCA Driven Pile Case History Database).

COST SAVING MEASURES:

After obstructions were encountered during PZ-40 installation with the APE Model 50 vibratory hammer that prevented the sheet piling from being installed to the required embedment depth, the pile probing program previously described was implemented. It should be noted that these obstructions were not addressed in the project specifications. After the completion of this probing program, several options were evaluated to finish the project. Data used to evaluate each option included: vibration estimates, pre-condition survey results, computer modeling results, and the monitoring data up to that point in time. The following is a brief summary of the evaluated options:

- **Larger Diameter Cofferdam Wall.** This option would significantly increase project costs from additional sheeting and installation and still would encounter debris (as shown in the probing plan in Figure 8. In addition, the project timeframe would have to be increased.

- Shorter Diameter Cofferdam Wall. This option would place the PZ-40 sheet piling next to the 1939 repair sheet piling. While this would reduce the number of sheets and therefore project costs, the engineering analysis showed that the remnants of the 1939 sheet piling were most likely significantly assisting in supporting the lighthouse compromised foundation. Therefore, it was decided to not potentially jeopardize the lighthouse by decreasing the cofferdam diameter.

- **Cut Off Piles at Refusal.** This option would provide poor protection for the lighthouse and potentially place the integrity of the cofferdam at risk.

- **Excavate and Remove Debris.** This option could potentially expose more of the existing lighthouse foundation to the Atlantic Ocean as well as undermine it.

- **Attempt to Drive Through Debris.** After detailed vibration analysis using the data collected from the monitoring program, it was determined that a larger vibratory hammer (APE Model 150) could punch through the debris without generating harmful vibrations. This option was chosen and successfully implemented.

The engineering evaluation of the various options showed that driving with a larger hammer and keeping the original design was the cost-effective option for this project.

SENSITIVITY TO THE ENVIRONMENT:
As previously described, the Morris Island Lighthouse is a well-known historic structure located near the entrance to Charleston Harbor. Over the years, the lighthouse has become iconic to Charleston. The inability to replace this structure was noted in the project specifications, which required the development of a detailed Vibration Control Plan as well as pre and post condition surveys. In addition, the project was located near the entrance to one of the busiest seaports on the U.S. Eastern seaboard. Therefore, additional rules and regulations relating to construction near shipping lanes had to be followed.

IMPLEMENTATION OF SAFETY INITIATIVES:
Safety was of the upmost concern for this project, given the difficult working conditions. Therefore, a rigorous project safety program was developed that exceeded the US Army Corp of Engineers safety requirements. Despite working in an extremely challenging and hazardous environment, Taylor Bros. Marine received a U.S. Army Corps of Engineers Contractor's Safety Award for the project.

BENEFITS TO THE PUBLIC OR OWNER:
As shown in the structure monitoring data over the course of the project, ***the installation of the sheet pile cofferdam provided immediate protection to the lighthouse***. In addition, the installation of the PZ-40 sheeting, associated template piling, and various dock piling did not damage the structure. This was verified by the post-condition survey, which showed no significant damage to historic lighthouse occurred during the project. An example of the protection provided is presented in Figure 13, which shows a wave breaking on the sheet pile cofferdam.

The new PZ-40 steel sheet pile cofferdam provides the historic Morris Island Lighthouse with the protection is needs from the Atlantic Ocean, allowing future foundation stabilization and renovation work and for future generations to enjoy its beauty.

Figure 13. Waves breaking over the Morris Island Lighthouse Sheet Pile Cofferdam.
Driven Piles Protecting the Past, Helping Preserve the Future.