# Port Infrastructure: Marine Commerce Terminal in New Bedford, MA

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## ABSTRACT

The Marine Commerce Terminal (MCT) in New Bedford, MA is the first port facility in the nation designed to support the construction, assembly and deployment of offshore wind projects, as well as handle bulk, break-bulk, container shipping and large specialty marine cargo. The MCT, which is located inside New Bedford Harbor and protected by an USACE hurricane barrier, is in close proximity to offshore wind planning areas along the East Coast that are under consideration for future development. The MCT consists of a 1,200-linear-foot bulkhead system with deep-water access and roughly 20 acres of port terminal space engineered to sustain mobile crane and storage loads that rival the highest capacity ports in the nation. The most demanding requirement of the terminal structure is supporting a ground pressure load of 4,100 psf and the maximized reach of fully loaded cranes (500 tonnes at a distance of 30 meters) to operate right up to the offshore edge of the platform and laterally for the entire 1,000 foot length of the newly constructed facility.

As part of construction, the project included the dredging and removal of approximately 280,000 cubic yards of contaminated sediment and the landside clean-up of 18,000 tons of contaminated soil caused by industrial waste generated during the 1930s and 1940s, a significant environmental benefit. Geotechnical challenges included high bearing pressures, maximizing beneficial reuse of dredged materials, and blasting near sensitive structures.

Construction of the MCT was completed in early 2015. This paper discusses the port bulkhead facility design including the uniqueness of the site, dredging considerations, structural design, and geotechnical engineering.

## INTRODUCTION

In 2009, the newly formed Massachusetts Clean Energy Center (MassCEC) was tasked with facilitating plans to integrate offshore wind into the Massachusetts energy landscape. One of MassCEC's first tasks was to assess the infrastructure needs that this new industry might have and determine where appropriate and beneficial infrastructure upgrades could facilitate the development of the industry. A critical component of the infrastructure required to support offshore wind is an appropriately designed port facility, and as such, the work described herein was commissioned by the MassCEC. Recognizing that the development of the first offshore wind staging port in the U.S. would require the skills of a diverse team of experts, the MassCEC constituted a Design Team to work on the new port facility terminal. Apex Companies, LLC (Apex) was the engineer of record with a team comprised of CLE Engineering, Inc. (CLE), which performed the structural design, GZA GeoEnvironmental, Inc. (GZA) which performed the geotechnical engineering, LeMessurier Consultants, which served as the Owner's representative, Fuss and O'Neil, for utility design and Aspera Associates to further support the development of the Marine Commerce Terminal (MCT).

The first step in developing plans for a port facility terminal was to identify a location. In 2010 MassCEC commissioned a study to identify the best Port within the Commonwealth to support the developing Offshore Wind industry. After a thorough evaluation of the State's five major Ports, the State determined that the Port of New Bedford had the most attributes that the Offshore Wind industry desired including but not limited to: protected harbor, shipping channel depth, overhead clearance, operational ability, exclusive use of port facility, berth length, shipping vessel water depth, wharf and upland yard area, rail access, highway access, and proximity to wind development areas (TetraTech EC, Inc., 2010). The Port of New Bedford was identified as the best opportunity for the State to capitalize on the significant shipping and fabrication activities that are associated with the installation of a Wind Farm. Further, a MCT at this site would fully support global shipping operations that go well beyond offshore wind.

The Port of New Bedford is on the south coast of Massachusetts, in close proximity to wind development areas. The terminal is north of the US Army Corps of Engineers' Hurricane Barrier which provides protection from hurricane storm surge. The site is directly south of South Terminal, an existing marine terminal facility, and includes areas of upland, intertidal and subtidal land.

## DESIGN CRITERIA FOR THE MARINE COMMERCE TERMINAL

The development of a MCT to support the offshore wind industry as well as global shipping and specialty marine cargo represented a great challenge, not the least of which was determining the correct specifications that would define the design process.


**Figure 1. Overview of MCT Site (image from Google earth)**

***Bulkhead and Quayside Design Criteria.*** In consideration of the European ports as well as criteria provided by potential users of the MCT, MassCEC developed design parameters for the facility that ensured it would meet needs of current and future wind farm installations. The Design Team learned from the knowledge that European developers had gained during their decade long development of the industry there. Direct correlations between European and U.S. applications, however, were inconclusive as no two applications were identical. As a result of the MCT's unique context, MassCEC and the Design Team independently identified many of the attributes that the facility would require for current and future offshore projects and future industry trends.

Potential users of the facility identified the ability for super lift cranes to transit laterally along the seaward face of the facility while carrying their loads as advantageous for improved efficiency of operations. Therefore, the design criteria included a structure capable of supporting a ground pressure load of 4,100 psf (20 t/sq meter) as well as "super lift" crawler cranes capable of picking 500 tonnes at a distance of 30 meters, and the more demanding feature of enabling their maximized reach by allowing the fully loaded cranes to operate right up to the offshore edge of the platform and laterally for the entire 1,000 foot length of the new facility.

***Dredge Design Criteria.*** Apex Companies, LLC developed berth designs to accommodate vessels likely to utilize the facility. The north end of the NBMCT was designed for ships up to 500 feet in length, with drafts of up to -30 feet (9.14 meter) MLLW. The ship berth is expandable up to 100 feet to the south, and up to 150 feet to the north. The southern 400 feet of the NBMCT is designed as a barge berth with a draft of -14 feet (4.27 meter) MLLW.

A total of approximately 900,000 cubic yards (cy) of sediment was dredged to complete the project design, including approach channels to the new marine facility and dredging at the berth adjacent to the new quayside to accommodate the types of vessels anticipated to be serviced by the Terminal. Of that, approximately 250,000 cy of sediment was contaminated with levels of PCBs and heavy metals that could not be reutilized within the project and would be extremely expensive to dispose of at a conventional landfill. In order to create a viable and cost effective solution to the contaminated sediment issue on the project, the project design incorporated the use of a Confined Aquatic Disposal (CAD) Cell.

***Geotechnical Criteria for Upland Facility.*** Gradations of acceptable dredged material were developed for reuse at backfill behind and in the cofferdam cells. Compaction of the materials was specified by vibrocompaction through the use of driving a probe with a vibrating hammer through the placed dredged materials. Various probe spacings were investigated and verified with the use of a drill rig and standard SPT tests. In this way, dredged materials were re-used on site and were able to meet the high crane bearing loads. Another aspect of the Upland Design included removal of existing fill and recompaction of the fill to specified densities.

## DESIGN OF BULKHEAD AND QUAYSIDE

There were several site related and conceptual design issues which needed to be weighed as a whole in order to determine the most cost effective approach to the project. The most significant site issue was the presence of extensive ledge rock underlying the site, at a range of elevations, overlaid with a variable layer of fragmented and highly fractured rock, and very dense glacial till populated with large boulders. The most significant design criteria were the capacity requirements up to the edge of the quayside and throughout the site to support heavy cranes.

Initial bulkhead and quayside concepts for the facility involved several different design types: king-pile wall, tied back sheeting, filled concrete cell, marginal wharf, and circular cofferdam cell wall. Each potential wall type was evaluated in comparison to the existing conditions at the site coupled with the facility design requirements determined during the concept design. The primary technical factors influencing the bulkhead design were the load bearing requirements at the quayside coupled with the presence of extensive rock and very dense till above the target dredge depth. In order to alleviate high soil loads that would occur near the face of the bulkhead, a shallow relieving platform was applied to all preliminary designs.

A layout schematic of the final cofferdam wall alignment for the new facility is shown in Figure 2. A cross-sectional diagram of the bulkhead and quayside design of the facility resulting from the final design process is shown in Figure 3.

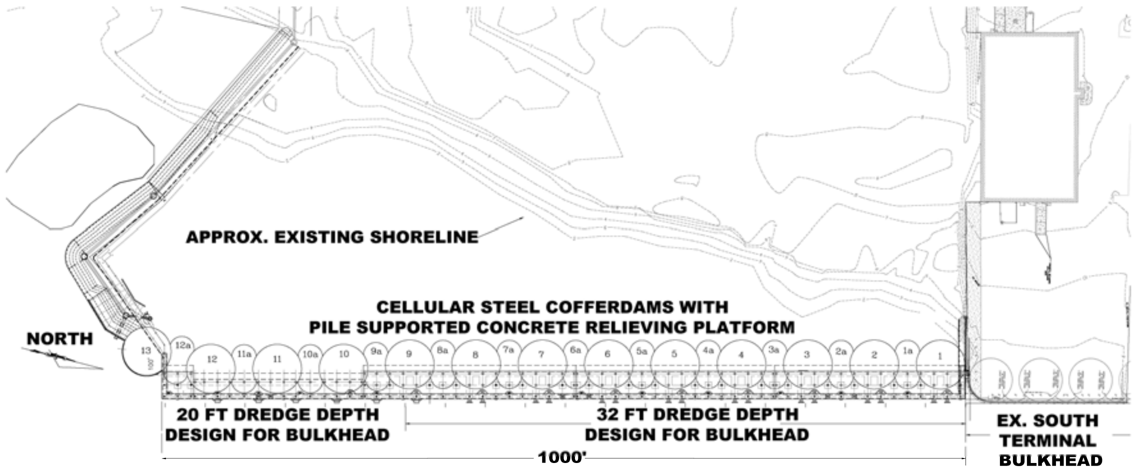


**Figure 2: Cellular Steel Cofferdams and Pile Supported Relieving Platform**

***Final Design.*** The final design of the bulkhead utilized 61 foot (18.6 meter) diameter steel cells at 82.9 feet (25.27 meter) centers, and minor cells are a 15.4 foot (4.7 meter) radius. Minor cells were constructed on both sides to allow pile driving and other equipment to work from on top of the cells during construction; thus providing schedule advantages for construction. The front third of the cell's sheet piles are driven to refusal, and the remainder of the sheet piles gradually stepped as they progressed inshore. The sheet piles for the front half of the cells were Skyline AS-500-12.7 sheets made of epoxy coated, 50 ksi A-690 corrosion resistant steel. Costs were reduced by using lighter AS-500-9.5 uncoated sheet piles for the back half of the cells.

Prior to installation of the cells, a layer ranging from two to seven feet of geotechnically unsuitable soil was removed. Final backfill after cell installation was predominantly select sandy soil from the dredging operations, which was vibro-compacted to improve the density. The fill was topped off with a variable layer of crushed stone, and topped with two feet of dense graded aggregate to provide a stable walking surface for the cranes to operate on.

The cells were topped with a hybrid shallow relieving platform/ marginal wharf, specifically designed to withstand the crane loads discussed earlier in this paper. The design provided a pile supported overhang of approximately 13 feet (3.96 meter) from the seaward most face of the cells, and an additional 4'-9" (1.448 meter) of stand-off distance was provided by the fender system. The overhang and fender system was configured to allow enough room for the construction of a shaped rock / soil slope from the toe of the sheet piles down to the berth dredge template. The finished slope was then protected from scour by the installation of a 16 inch precast concrete mattress. It can be seen from Figure 3 the design allowed for the unique feature of allowing the cranes to work right up to the face of the bulkhead with a lifting limit of 500 tonne, at a radius of 30 meters, which would allow for the loading and off-loading of the heaviest components of offshore turbines from ships and support vessels. Figure 4 shows the site during cell construction.

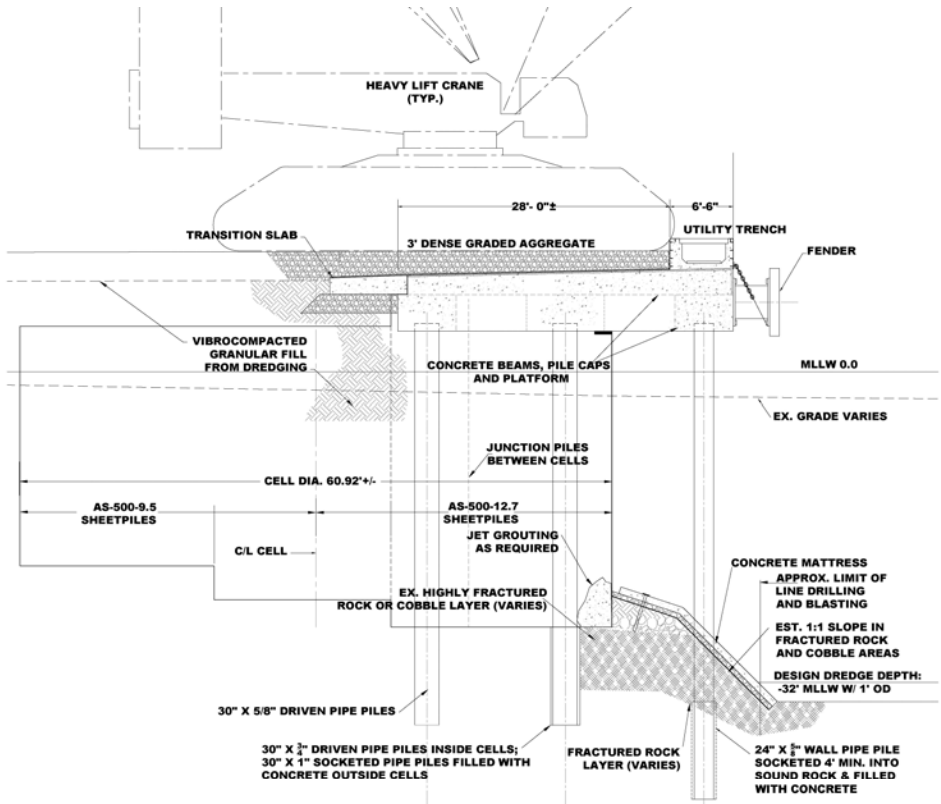


**Figure 3. Final design section of deeper draft bulkhead (dredging to -32, stepped circular cells, overhanging pile supported platform and toe scour protection).**

***Overcoming Design and Site Challenges for Structure.*** One notable constructability issue that the Design Team faced was the known presence of a considerable number of boulders and fractured rock within the soil column. The flat sheets that make up the cells have a very low section modulus individually, and it is only in their interconnection with each other (in the formation of the circular cell) that they obtain the strength of the whole. To obtain this unified strength the sheet piles must be driven individually in a specific sequence to assure complete interlocking with each adjoining sheet for the entire length. However, because of their relatively low strength as individual sheet piles, they are prone to damage during the driving process. They are particularly vulnerable to bending when they strike buried boulders. There are few options available if or when this occurs, because if an obstruction below one or more of the sheets does not allow the sheet to be driven to design depth (i.e. it meets refusal above the design toe elevation), then the strength of the entire cell is affected. To further complicate matters, one of the features unique to driving circular sheet pile cells is that a sophisticated driving template must first be put in place and carefully aligned, then leveled to maintain the circular shape and the interconnected pattern of the overall pattern of all of the cells. Once this circular template is placed, then the entire circle of sheet piles must be "threaded" together around the template to form the circle for what will become the cell wall.

**Figure 4. Aerial View of Cell Construction in Progress**

The problem that arises is that once the template is in place, and the ring of sheets installed, and then driving is initiated, if an obstruction were encountered during this phase of the driving, then it would become very costly and time consuming to remove all or part of the cell wall as well as the template to allow the removal of the obstruction. Knowing this, it became obvious to the Design Team early on that because of the known presence of sizable rocks within the soil column, a reliable and cost effective method would have to be devised to locate and remove as many obstructions as possible in advance of the cell construction.

The Design Team specified a pile probe exploration program that was part of the construction contract, which included probings to refusal at an interval of three feet around the full perimeter of each cell. The selected contractor elected to utilize a sizable vibratory hammer with a single H pile (HP14 x 117), clamped to the jaws hanging vertically from a barge mounted crane. The crane had an RTK-GPS mounted at the top of the boom for positioning, and a GPS navigation software program with a heads-up display for the crane operator to align each probe. This exploration program required an investment in over 1,800 probes, and yielded project savings that far outweighed the cost of the probing program.

The procedure was relatively simple: the operator could see where each probe was to be placed on the computer screen, and with the help of a crew member could place the tip of the H-pile with relative precision (1'+/-), then vertically plumb the pile in the X-Y directions. Once the pile was plumbed they would simply activate the hammer and vibrate the pile to the design depth. An engineer recorded each location, and observed the depth of any slowing of the probe during its decent or skewing of the probe that might indicate a physical obstruction. All of the data was then plotted in an AutoCAD template of the project site, and the data from each obstruction reviewed. A profile along the circumference of each cell was developed and a table was generated to allow the contractor to go to the designated obstruction locations and remove them. The probing program was considered very successful. It located a considerable number of buried obstructions; it was roughly determined that at least 95% of the potentially problematic obstructions were found and removed in advance of pile driving, which in itself resulted in viable savings in time and cost to all parties involved.

**Figure 5. Pile Probe Exploration for Obstructions in Progress**

***Interlock Strength and Testing.*** The use of circular steel cell cofferdams to support ultimate and future working loads of the magnitude called for on this project pushes the limits of currently available materials for construction of sheet pile cells. The major issue that is encountered in the use of cells for heavily loaded sites is "Hoop Tension", which occurs in the cell interlocks, and vertical shear within the cell which would be the result of extreme un-equal loading. The more important of the two issues is the interlock tension, and there is an unusual performance issue with interlocks in tension that must be considered when the design approaches the advisable design limits of the material. The most common failure of a cell is the pulling apart of an interlock, which normally occurs in the lowest third of the cell, where soil pressure is at its highest. This failure is caused by the outer jaw of the interlock which grips around its counterpart "knuckle" of the joining sheet (see Figure 6 below) opening and thus releasing the adjoining sheet. It is also known from experience that the junction-pile (where the cells are joined, or the "Y" connector) is apparently the most highly loaded location, because it is the most common point of failure. Both of these issues were carefully addressed in the design.

The first item addressed was the inherent weakness in the "Y" branch itself, which for this project was specially reinforced using additional plates, installed by the manufacturer, as shown in Figure 6. For the interlock issue, a more rigorous testing program of the interlock "pull-apart" strength was specified by requiring laboratory coupon testing of every sheet that would be used in the manufacture of the outboard junction piles.

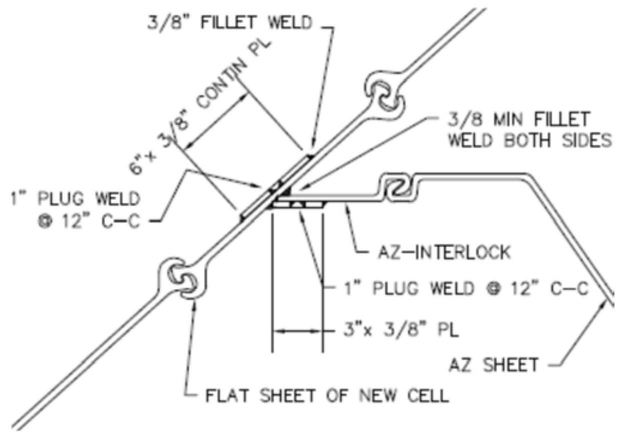


**Figure 6. Detail showing interconnecting knuckles of flat sheets, and the reinforcement used to strengthen the junction pile "Y" connector**

The increased testing protocol used for this project revealed another unusual performance related issue with the sheet pile interlock. While all of the sheet piles supplied by the manufacturer passed the design minimum "pull apart" load test by a satisfactory margin, it was noted that the pull-apart strength is not directly correlated to the strength of the metal used in the manufacture. The following are some general statistics related to the testing:

Of 62 samples tested as of this writing, the yield strength of the steel itself varied from a low of 5% above the minimum yield, to as high as 38% above minimum yield.

Of these samples:

38% (24 Samples) ranged from 5% to 19% above minimum yield;
55% (34 samples) ranged from 20% to 29% above minimum yield;
7% (4 samples) were above 30% above minimum yield.

Interlock "pull-apart" yield strength ranged from 1% to 123% above the minimum requirement; however these percentages were totally inter-dispersed among all of the samples from the lowest to the highest yield, rather than among the samples that tested as having the highest yield strength. For instance, of the 38% (24 samples) that tested from 5% to 19% above minimum yield strength: 7 samples had pull-apart yield from 1% to 9% above minimum; while the remainder were distributed from 10% to 113% above minimum with no direct correlation to the tested steel yield strength.

Of the group of 55% (34 samples) that tested from 20% to 29% above minimum yield strength; 4 samples had pull-apart yield from 3% to 9% above minimum; while the remainder were distributed from 10% to 133% above minimum, again with no direct correlation to the tested yield strength. The most surprising was the 7% (4 samples) that were 30% or higher above minimum yield. All (100%) only had pull-apart yield strength of 1% to 9% above the minimum (among the lowest of the test results); again demonstrating the lack of correlation between material yield and interlock strength.

Our conclusion is that this unpredictability of interlock pull-apart strength must be accounted for when designing heavily loaded steel cell cofferdams. Therefore laboratory testing of not only minimum yield of the metal, but also interlock "pull-apart" is extremely important. Specific additional reinforcing and testing should be considered on critical or highly stressed components.

***Overcoming Geotechnical Site Challenges.*** Geotechnical challenges included designing the site for high crane bearing pressures and blasting near sensitive structures. Many options to produce high bearing capacity were investigated including ground improvement, deep foundations, excavation and replacement, and reinforcement with geosynthetics. High groundwater, environmental concerns, and schedule made many options impractical. Concerns that were investigated for the geofabric included pull out, double seam installation procedures, and one-directional strength for high strength geofabric. Concerns for the geogrid included proprietary strength properties and proprietary software. It was found that the engineering support for the geofabric and geogrid manufacturers evaluated different failure modes but not all failure modes. It was determined that geosynthetic reinforcing did not have a significant benefit over placing compacted fill without the reinforcing, and some concerns could not be reconciled.

Rock blasting required to reach the dredge elevations was required in close proximity to the USACE hurricane barrier, which is an earthen embankment constructed in the 1960's. Seismic analyses were performed to predict the impact of vibrations from blasting to address the Army Corp's concerns over liquefaction or settlement of their structure. Blast weight limits as a function of distance from the structure were established for the project based on the analyses. A test blast program was conducted to verify the assumed attenuation relationships. Real time monitoring of the vibrations and pore pressures in the structure were conducted by the design team using remote systems with no exceedances in threshold values.

## REFERENCES

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