ENVIRONMENTAL DREDGING, CAPPING AND BENEFICIAL USE OF SOLIDIFIED SEDIMENTS: A PROJECT CASE STUDY

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ABSTRACT

Environmental dredging usually produces dredged materials that must be transported off site for treatment and disposal. Transport and off-site disposal incur high costs, entail disruptive truck traffic, and result in high greenhouse gas emissions. On-site methods such as cement solidification of dredged sediments and capping of remaining sediments can greatly reduce, or in some cases eliminate off-site transport and disposal. This project case study presents one solution involving a combination of environmental dredging, capping, and solidification of dredged sediments for beneficial on-site use. The project was located in a slip in New Bedford, Massachusetts. The specific focus of this paper are the issues of the sediment’s physical characteristics and the dredging and capping tolerances that were designed versus those that were achieved for the work. The primary environmental concern associated with the sediments in the slip was sheen produced by residual coal tar from a former manufactured gas plant that had previously been located adjacent to the slip. An environmental clamshell was used to mechanically dredge sheen-producing sediment from the area and to allow for cap materials to be placed. The dredging was done in the wet within a movable work zone turbidity curtain and a fixed outer turbidity curtain. A 2-foot thick protective cap was then placed, consisting of successive layers of a clay-aggregate barrier, gravel, armor stone, and benthic habitat sand. The specifications for dredging and capping were carefully crafted to ensure that the project goals were achieved while remaining constructable and promoting cost-effective operations for the marine services contractor. Of particular concern were the settling characteristics of the dredged sediment which would be placed into the adjacent slip. Another concern were the tolerances required to prevent dredging of too great a volume of sediment which would have exceeded the on-site placement capacity. All of the dredged sediments were placed in two on-site cells constructed within a former small slip area. The dredged sediments, together with in-situ sediments within the cells, were solidified by adding a cement/bentonite slurry and conducting auger mixing. The solidified material met quality control criteria and allowed for its beneficial use as structural subgrade material suitable for the end use as a driveway or parking area. The project was completed in accordance with the schedule in October, 2011.

Keywords: beneficial use, coal tar, constructability, contaminated sediments, dredging tolerances, settling, solidification, turbidity control.

INTRODUCTION

Subsurface marine sediment in a portion of New Bedford Harbor in Massachusetts was impacted by tar-residuals generated at a former manufactured gas plant (MGP) and coal tar processing facility that operated adjacent to the harbor from 1880 through the mid 1960’s. The waterfront area adjacent to the former MGP consists of an Inner Slip and Outer Slip of approximately 4.5 hectares (11 acres). It is located along a primarily industrial portion of the Acushnet River waterfront in New Bedford Harbor. Figure 1 shows the general location of the site, and Figure 2 shows the Inner Slip and Outer Slip areas.
Figure 1. Site location.
The tar affected sediment was located within the boundaries of the U.S. Environmental Protection Agency (EPA) New Bedford Harbor Superfund site, where PCBs are widely present in sediment. Figure 3 shows the site area within the much larger New Bedford Harbor Superfund Site. The constituents of MGP tar contain polycyclic aromatic hydrocarbons (PAHs), which are of potential environmental and human health concern. PAHs were detected in sediments in portions of the Outer Slip that did not contain visible tar or produce sheens, but at sufficiently low concentrations that they posed a much lower risk than the PCBs present in the sediments. The EPA had already determined that removal of sediments containing PCBs in this portion of the harbor was not required. Therefore, the removal of PAH-containing sediments was limited to the removal of tar-impacted sediments.

The final goal of the work, in accordance with an agreement with the Massachusetts Department of Environmental Protection, and the US Environmental Protection Agency, was to remediate the slip areas such that the top 0.3 m (1 foot) no longer contained coal-tar material and that sheens would no longer be produced.

In addition to this regulatory-driven environmental goal, the remediation needed to result in the same or deeper draft available for the ship fueling operations in the slip area. Secondary constraints with regard to the dredging were imposed by the limited capacity for dredge spoils on site, and the limited structural stability of the adjacent bulkhead walls.
This project case study presents one solution involving a combination of environmental dredging, capping, and solidification of dredged sediments for beneficial on-site use. The specific focus of this paper is the issue of the sediment’s physical characteristics and the dredging and capping tolerances that were designed versus those that were achieved for the work.

PERMITTING

The following six permits were required for this remedial action:

- Response actions at the Site were conducted under a Tier 1B Permit that was issued by the Massachusetts Department of Environmental Protection (MassDEP) for this Release Abatement Measure (RAM).
- In accordance with the Massachusetts Wetland Protection Act Order of Conditions (OOC) for the RAM was issued by the New Bedford Conservation Commission
- A Chapter 91 Massachusetts Public Waterfront Act Waterways License was issued by the MassDEP.
- A 401 Water Quality Certification was issued by the MassDEP.
- An Energy and Environmental Affairs (EEA) Certification was authorized under The Massachusetts Environmental Policy Act (MEPA).
- A Category 2 General Permit for the RAM was issued by the United States Army Corps of Engineers (USACE)

DREDGING AND CAPPING DESIGN

The conceptual design was for dredging and capping of the Outer Slip, and in-situ solidification (ISS) of the sediments in the Inner Slip and the dredged sediments from the Outer Slip which were all to be placed in the Inner Slip. The design process first identified the design constraints imposed by site-specific factors. A pre-design investigation was then conducted, which provided the data used to establish the limits of work and the handling characteristics of the sediments. A narrative work plan, construction specifications and design drawings were then prepared. These design documents were used to obtain approval from environmental regulatory agencies, to obtain a US Army Corps of Engineers permit, and to obtain bids and guide the remedial construction.

Constraints on the Dredging Design

The primary goal of the dredging design was to remove all sediment in the top 0.3 m (1 foot) of the Outer Slip area that contained coal-tar material. The sediment in the Inner Slip would not be dredged, but would be solidified, as described later in this paper. The limits of dredging and dredging methods were constrained by the requirement that all dredged sediment would be placed in the Inner Slip for solidification. No sediment was to be transported off site.

The capacity of the Inner Slip therefore provided an upper limit to the quantity of sediment that could be dredged from the Outer Slip. Of particular concern were the settling and consolidation characteristics of the dredged sediment which would be placed into the Inner Slip. Expansion of the volume of dredged sediment in comparison to the in-place volume would need to be taken into account in the volume capacity estimates for the design. Other concerns were the dredge depth tolerances and tolerances on horizontal limits to be specified to the contractor to prevent dredging of a volume of sediment greater than the Inner Slip capacity. Accurate of information on the horizontal and vertical extent of tar-containing sediments in the Outer Slip, and the actual sediment depths in the Inner Slip were therefore critical for this design.

An additional constraint on the dredging design was imposed by the need to maintain the structural stability of the existing steel sheet pile bulkhead, which formed the northern border of the area to be dredged. A geotechnical analysis was conducted to determine the depth of dredging permissible next to the bulkhead in order to maintain a sufficient factor of safety.

A final constraint on the dredging design was that the final elevation of the sediment surface would need to allow sufficient draft for the boat traffic that would use the Outer Slip.
The additional data required regarding the physical characteristics of the sediment and a more accurate extent of tar impacts were obtained by conducting a pre-design investigation.

**Pre-design Investigation**

A pre-design investigation was conducted which included a bathymetric survey of the Inner Slip and Outer Slip, sediment cores collected for field logging, field testing, and laboratory analysis.

An initial bathymetric survey was conducted of the Inner and Outer Slips. The purpose of the bathymetric survey was to determine sediment elevation throughout both areas. The survey was conducted using a GPS, an echo sounder and transducer, and an on-board computer running hydrographic survey software.

Although previous investigations had determined the approximate extent of impacts, an additional 27 cores were collected to further define the vertical and horizontal limits of impacts in the Inner and Outer Slips. The sediments were characterized as soft silt, silty sand and sands, with shell fragments. Tar blebs and tar veins were observed in the silt and sand matrix in 10 of the cores. The tar was characteristic of MGP residual material and consisted of a non-aqueous phase liquid that caused a sheen when disturbed in water.

Laboratory testing included geotechnical index testing and consolidation testing, and PCB analysis. The consolidation testing was conducted by modifying a method described by the US Army Corps of Engineers (U.S. Army Corps of Engineers, 1987). Rather than creating a slurry in accordance with the method, 317 grams of sediment sample was mixed at the as-received moisture content of 63.9% and placed into 3 liters of water collected from the site, within a 5-liter graduated cylinder. This simulated the placement of dredged sediment into the Inner Slip Cells. The settling and consolidation of the column was then measured over time. Table 1 provides the settling test data and Figure 4 shows the results plotted over time.

**Table 1. Consolidation testing results (Courtesy of GeoTesting Express, Inc.)**

<table>
<thead>
<tr>
<th>As-Received Material:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content, %:</td>
<td>63.9</td>
</tr>
<tr>
<td>Bulk Density, lb/ft³:</td>
<td>96.5</td>
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<tr>
<td>Dry Density, lb/ft³:</td>
<td>58.9</td>
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<tr>
<td>Specific Gravity (assumed):</td>
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<table>
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<th>Settling Column:</th>
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</thead>
<tbody>
<tr>
<td>Mass of Wet Soil, grams:</td>
<td>317</td>
</tr>
<tr>
<td>Mass of Dry Soil, grams:</td>
<td>193</td>
</tr>
<tr>
<td>Mass of Site Specific Water, grams:</td>
<td>3076</td>
</tr>
<tr>
<td>Height of Soil and Water at Start of Test, in:</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data:</th>
<th></th>
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<tbody>
<tr>
<td>Elapsed Time, min</td>
<td>Height of Interface from Bottom, in</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>16.2</td>
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<tr>
<td>21</td>
<td>2.80</td>
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<td>32</td>
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<td>2810</td>
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The results of these tests indicated that the sediment in the Outer Slip would settle rapidly after placement through the water column in the Inner Slip cells. No special settling agents or procedures would be required to enhance settling and final consolidation. However, the water in the Inner Slip would be turbid and turbidity control of water from the Inner Slip would be an important design consideration.

Dredging Tolerances and Constructability

The specifications for dredging and were carefully crafted to ensure that the project goals were achieved while remaining constructable and promoting cost-effective operations for the marine services contractor.

The horizontal limits of dredging were defined such that the contractor was required to dredge to the limit of work, which was defined by the results of the pre-design investigation.

The appropriate vertical limits were more complex to determine. The results of the pre-design investigation showed that tar-impacted sediment occurred shallow sediments from 0.3 meters (1 ft) to 0.6 meters (2 ft) in depth in a contiguous area in the Outer Slip. Tar-impacted sediments were found at greater depths in two areas within this contiguous area. Calculations of Inner Slip capacity and the volume of impacted sediment in the Outer Slip revealed that more than sufficient capacity existed for the shallow sediment to be removed, in conformance with the mandated remedial goal of the top 0.3 meters (1 ft) to be free of tar-containing sediment. The deeper tar-impacted sediment could also be removed and placed into the Inner Slip, which would be a prudent measure to remove material which had the potential for producing sheen, through ebullition or other migration processes. The maximum depth of dredging was 2.1 meters (7 ft). The sloughing that would occur during dredging also was taken into account by estimating a final slope of 1 vertical to 3 horizontal. The slope was based on the geotechnical index properties of the sediment and experience from similar dredging projects. It was also determined that a cap over the excavated sediment would be a prudent measure to provide containment that would prevent any remaining tar-containing material from causing a surface water sheen. The thickness of the cap would have to be compensated for by dredging additional sediment so that the required shipping draft could be maintained.

The final dredging cut lines were thus determined and appropriate tolerances were established. A minimum cut line was established to provide for removal of the tar-impacted sediments and sufficient draft. A maximum cut line was also established so that the capacity of the Inner Slip would not be exceeded, so that the structural stability of the steel bulkhead would be maintained, and to control remediation costs. The difference between the minimum cut line and the maximum cut line was 0.3 meters (1 ft) in all of the dredged area, except adjacent to the bulkhead, where it was 0.15 meters (0.5 ft), to account for the more critical depth control required in that area. It was determined that the Inner Slip capacity would not be exceeded if the average actual cut line was 0.15 meters (0.5 ft) below the minimum cut line. This degree of precision in the dredging was determined to be readily constructable by reference
to previous, similar projects and consultation with environmental dredging equipment manufacturers. The incentive to the contractor for not exceeding the maximum cut line was provided by not allowing payment for dredging of material below the maximum cut line.

Capping Design

A 2-foot thick protective cap was designed, consisting of successive layers of 0.15 meters (0.5 ft) of clay-aggregate barrier, 0.15 meters (0.5 ft) of gravel and armor stone, and 0.3 meters (1 ft) of benthic habitat sand.

The clay-aggregate barrier was selected as a protective barrier that would isolate potential sheen-producing sediments from the surface sediments in the benthic habitat sand. The material was further specified as AquaBlok® 3070SW#8. It was determined to be compatible with saline water conditions at the site, as it contains two types of clay that are specially formulated for marine application. Both bentonite clay, a high-swell Wyoming sodium (Na) bentonite (montmorillonite), and attapulgite clay, a palygorskite (hydrated aluminum-magnesium silicate). The product, when hydrated is reported to achieve a permeability of $1 \times 10^{-7}$ to $1 \times 10^{-8}$ cm/sec (AquaBlok, 2011).

The gravel and 3-inch armor stone layer was included to provide additional protection against erosion of the barrier. The primary cause of potential erosion would be propeller wash from the boats using the Outer Slip.

The one foot of benthic habitat medium sand was required by regulatory agency to provide sufficient material for benthic habitat to be re-established following the dredging event.

The cap limits extended approximately 10 feet beyond the estimated edge of visually observable tar in shallow sediment. Figure 5 shows the final design of the dredging and capping areas.

**Figure 5. Design of sediment remedial action.**

IMPLEMENTATION OF DREDGING AND CAPPING

Prior to dredging a pre-dredging bathymetric survey was conducted to gain more accurate and up-to-date surface elevation data than was obtained in the pre-design investigation a year earlier. The design drawings were then adjusted slightly to account for these new data.

Two steel sheet-pile walls were constructed across the width of the Inner Slip to create two containment cells for the dredged sediments. An environmental clamshell was used to mechanically dredge the sediment from the area. A transducer and GPS device attached to the clamshell bucket allowed tracking of the location and progress of dredging in real time. Visualization software, the Clamvision® system (Cable Arm, Inc.) allowed the dredging crane operator to accurately place the bucket. Figure 6 is an image from the computer screen located in the crane cab during the operation of the GPS system at this site. Soundings were taken by plumb line throughout the day provided additional checking of depth and position to achieve the required limits of dredging. Charter Environmental, Inc. (Charter) of Boston, Massachusetts, was the general contractor for the work, and dredging and capping were conducted by their sub-contractor, AGM Marine Contractors, Inc. (AGM) of Mashpee, Massachusetts.
Midcourse Correction to Prevent Excessive Dredging

Volume checks after the first week of dredging determined that the Inner Slip capacity might be exceeded unless less dredged material was generated. A review of the dredging record indicated that most of the dredged area was cut to the maximum dredge depths, rather than the average depth between the minimum and the maximum. The accuracy of the positioning and depth control of the dredge bucket was much greater than anticipated in the design. A midcourse correction to the dredging procedure was made so that the dredging to the minimum depth was targeted for the remainder of the dredging. This proved to be a successful adjustment and the capacity of the Inner Slip was not exceeded.

Dredging Design Limits Achieved

Between July 8 and July 26, 2011, AGM Marine Services dredged sediments from the designated areas of the Outer Slip and placed the materials within the Inner Slip. Approximately 1,032 cubic meters (1,350 cubic yards) of dredge spoils were removed from the Outer Slip and placed into the Inner Slip. Final bathymetric surveys were conducted to confirm conformance with the designed limits of sediment removal.

Fill and Cap Placement

Between August 3 and September 6, 2011, AGM placed sand fill in the Outer Slip to prepare for the placement of sub-aqueous cap materials. Between September 10 and October 6, 2011, AGM placed an approximately 2- to 4-foot-thick subaqueous, cap over the tar-impacted area in the western portion of the Outer Slip. Cap materials were placed using the environmental clamshell bucket, as shown in Figure 7. The materials used and their approximate thicknesses are shown in Figure 8.
Environmental, Health and Safety Controls During Dredging and Capping

The slip area was located in an active commercial ship and recreational boating area. In addition, the working area for the remediation was located adjacent to a waterfront restaurant and an operations center for the local utility company. Stringent environmental, health and safety controls were implemented for this project.

Warning buoys with flashing lights were placed in the outer slip area in accordance with the New Bedford Harbor Master’s requirements. No shipping safety incidents occurred during the work.

A turbidity curtain and floating absorbent boom were placed at the far limits of the Outer Slip dredging and capping area. These environmental and safety controls stayed in place for the duration of the in-water work. In spite of unusually high wind and tide conditions, the turbidity curtain, which was attached to the slip bulkhead and also
anchored, was maintained in position throughout the work. No turbidity exceedances above background occurred at monitoring stations established at the turbidity curtain.

A second, moveable turbidity curtain with an absorbent boom, was installed on a floating rigid steel frame. The moveable curtain formed a square area in front of the dredging barge such that all dredging could be conducted within this primary turbidity curtain. The moveable curtain was found to be effective in containing nearly all turbidity and sheen produced during the dredging. The fixed and moveable turbidity curtains are shown in Figure 9. The effectiveness of the movable curtain to control the migration of sheens during dredging can be seen in Figure 9. The movable turbidity curtain is shown in Figure 10.

![Figure 9. Fixed, outer turbidity curtain and moveable turbidity curtain during dredging.](image1)

![Figure 10. Moveable turbidity curtain being lowered into position.](image2)
The dredging was conducted using an environmental bucket manufactured by Cable Arm, Inc. This enabled enclosure of the dredged sediments and control of turbidity during dredging. Air emissions were also controlled by use of sprayed foam over the dredged materials, as shown in Figure 11.

![Figure 11. Use of encapsulating foam to control air emissions from the dredged sediments containment cell.](image)

Air monitoring for dust and volatile organic compounds was conducted during the dredging work. No air monitoring exceedances or odor complaints were registered during the project.

**DESIGN OF ON-SITE SOLIDIFICATION OF DREDGE SPOILS**

Environmental dredging usually produces dredged materials that must be transported off site for treatment and disposal. Transport and off-site disposal incur high costs, entail disruptive truck traffic, and result in high greenhouse gas emissions. On-site methods such as cement solidification of dredged sediments can greatly reduce, or in some cases eliminate off-site transport and disposal. In the case of this project, all dredged sediment from the Outer Slip was solidified with the in-situ sediment in the Inner Slip.

The design of this portion of the remedy entailed the establishment of performance criteria for the solidified mass, development of a solidification mix design that would meet these criteria, and selection of appropriate methods for implementation.

The remedial goal for the site was to eliminate sheens caused by coal tar present in the sediments. Cement solidification of the sediments would physically encapsulate the impacted sediments in a solid monolith of low permeability that would effectively meet this goal. The performance criteria that were established to ensure this goal was met were low permeability as and Unconfined Compressive Strength (UCS).

A solidification mix design evaluation was conducted on bulk sediment samples by Kemron Environmental Services (Kemron) of Atlanta, Georgia. The mix design evaluation found that the sediment responded similarly to other silty soils that had been tested for previous ISS projects. It was determined that a slurry injection resulting in 8% to 10% type I Portland Cement would be sufficient to solidify the sediments and would result in a solidified mass of appropriate strength and low permeability.

The appropriate methods for implementation took into consideration the site-specific requirements of the project. The depth of bedrock refusal in previous sediment cores and on-shore borings in the area was between...
approximately 20 and 30 feet. This depth and the requirement for rigorous mixing using a well-established technology led to the selection of auger mixing in overlapping columns as the preferred method of solidification.

IMPLEMENTATION OF SOLIDIFICATION

Between August 25 and October 1, 2011, Geo-Solutions Inc. (Geo-Solutions) of Pittsburgh, Pennsylvania, as a subcontractor to Charter, performed the in-situ solidification (ISS) of the Inner Slip. Geo-Solutions used a Delmag ISS Drill Rig fitted with 3-foot and 8-foot diameter augers to inject and mix a Portland cement slurry into the dredged spoils and underlying sediments in the Inner Slip. Geo-Solutions performed the ISS by advancing the columns to bedrock refusal. Refusal was generally encountered at depths between approximately 20 to 30 feet. After advancing a column to refusal, Geo-Solutions then completed three mixing passes over the length of the column. Approximately 7,000 cubic meters of sediment were solidified. The solidification process was monitored by collecting samples of the in-situ slurry, forming them into test cylinders, and testing them. The monitoring test cylinders met the criteria for low permeability and sufficient strength. The implementation of ISS is shown in Figure 12. The advancement of overlapping ISS columns is shown in Figure 13.

Figure 12. ISS rig in operation in the Inner Slip.

Figure 13. ISS rig advancing overlapping columns in the Inner Slip.
Environmental, Health and Safety Controls During Solidification

The controls put in place for the dredging and capping work were continued during solidification. Air monitoring for dust and volatile organic compounds was conducted during the solidification work. The odors and volatile organic compound field measurements near the work were generally lower than during the dredging work. No air monitoring exceedances or odor complaints were registered during the project.

Final Cover and Site Restoration

Once solidification was completed, the Inner Slip was covered with a geotextile demarcation layer and then a 1-meter (3-foot) cover of clean, imported sand and gravel was placed. This material was placed to eliminate potential contact with the solidified Inner Slip material. This final cover was completed on October 11, 2011.

ONGOING MONITORING

Daily monitoring for sheen related to tar-contaminated sediments in the Outer Slip was performed during the period after the subaqueous cap was completed in October 2011 through the beginning of November 2011. Since the completion of the ISS work and the placement of the subaqueous cap, tar-related sheens have not been observed emanating from the Inner Slip or from the area of the subaqueous cap in the Outer Slip.

In accordance with the provisions of the project permit, ongoing monitoring activities will include inspection of the Inner Slip soil cover and Outer Slip sub-aqueous cap once a month for 6 months to confirm that the subaqueous cap is meeting its objectives. If monthly monitoring indicates that conditions are stable, the site will be closed out with a standard use restriction provision, in accordance with the project permits.

CONCLUSIONS

This remedial action at the New Bedford Harbor MGP site provides an example of a combination of dredging, capping and solidification of dredged materials as a creative and effective remedy. It achieved the remedial goals of 1) removing tar-impacted sediment within 1 foot of the sediment surface and 2) preventing tar-related sheen on surface water of the Outer Slip caused by residual tar-impacted sediment.

Dredging and capping accuracy were greater than anticipated. The dredging depth tolerance between minimum and maximum depths could have been more stringent than the 0.3 meter (1 ft) tolerance provided for most of the dredging area. A target depth of just 7.5 cm (3 inches) below the minimum dredging depth would have been constructable under the conditions encountered at this site.

Beneficial use of contaminated dredged sediments can be obtained by properly designed and permitted cement solidification. In this example, the solidified mass was used to remediate and fill a slip area, which can now be used beneficially. The remediated area has sufficient stability to allow parking lot construction or other similar use to occur on top of the gravel cover placed over the solidified sediment.

REFERENCES


CITATION