DESIGN OF THE CAMPBELL SHIPYARD SEDIMENT REMEDIATION PROJECT, SAN DIEGO, CALIFORNIA

T. S. Wang P.E.[1], M. Whelan P.E.[2], D. Keith R.G.[3], J. Verduin P.E.[4] and P. Brown[5]

ABSTRACT

The former Campbell Shipyard site is located on San Diego Bay and owned by the Port of San Diego. In 1995, the California State Regional Water Quality Control Board (RWQCB) issued a Cleanup and Abatement Order (CAO) requiring cleanup of sediments over approximately 3.7 hectares (9.2 acres) offshore of the site, due to the presence of metals, hydrocarbons, PAHs, PCBs and TBT. In-place capping of impacted sediments with targeted dredging was selected as the preferred remedy due to its environmental protectiveness, constructability, cost-effectiveness, and consistency with current and planned site uses.

The Campbell Shipyard remedial design needed to account for the fact that the site is in an active industrial area with regular vessel activities, and also needed to address the concerns of multiple stakeholders. In particular, the design needed to account for a number of key technical challenges:

- Designing a clean sediment cap to isolate underlying chemicals from the environment and the water column.
- Protecting the cap against potential erosion from vessel-generated propeller wash, ship generated waves, tidal currents and wind-waves.
- Providing sufficient water depths for ongoing container ship operations at the adjacent Tenth Avenue Marine Terminal (TAMT).
- Ensuring that the project could be successfully constructed without impeding (or being impacted by) traffic to and from the TAMT facility.
- Providing mitigation for loss of existing eelgrass beds and creating a stable, protected area at shallow subtidal elevations for this purpose.
- Retrofitting the existing seawall and other structural features at the site to meet seismic standards.

The final design incorporated these key design criteria against construction sequencing needs, and balanced the pros and cons of using method vs. performance specifications to provide a more biddable project while still requiring appropriate control of key construction elements.

Keywords: Contaminated sediment, capping, erosion protection, dredging, mitigation, sediment management.

INTRODUCTION

Purpose of this Paper

Designing a remedial solution for the Campbell Shipyard site required a very site-specific and tailored remedial solution to meet the many stakeholder objectives. This paper will discuss how the project design addressed a number of key technical design issues, incorporated unique construction sequencing measures, and utilized prescriptive vs. performance-based specifications for some of the significant and challenging construction elements.

[1] Partner, Anchor Environmental L.L.C., 1423 Third Avenue, Suite 300, Seattle, Washington 98101, USA, T: 206-287-9130, Fax: 206-287-9131, Email: twang@anchorenv.com.

[2] Senior Engineer, Anchor Environmental CA L.P., 28202 Cabot Road, Suite 620, Laguna Niguel, California 92677, USA, T: 760-845-2983, Fax: 510-663-9884, Email: mwhelan@anchorenv.com.

[3] Associate Geochemist, Anchor Environmental L.L.C., 803 Government Street, Suite C, Mobile, Alabama 36602, USA, T: 251-441-0621, Fax: 251-432-0117, Email: dkeith@anchorenv.com.

[4] Partner, Anchor Environmental L.L.C., 1423 Third Avenue, Suite 300, Seattle, Washington 98101, USA, T: 206-287-9130, Fax: 206-287-9131, Email: jverduin@anchorenv.com.

[5] Environmental Specialist, Port of San Diego, P.O. Box 120488, San Diego, California 92112, USA, T: 619- 686-6597, Fax: 619-686-6467, Email: pbrown@portofsandiego.org.

The content of this paper is based on the project's Basis of Design Report (Anchor 2004).

Site Description

The former Campbell Shipyard site is located on the northeastern shore of San Diego Bay between the San Diego Convention Center and the Tenth Avenue Marine Terminal (TAMT), at Eighth Avenue and Harbor Drive (Figure 1). This facility is owned by the Port of San Diego (Port) and was first used for industrial operations in 1926 with the Campbell Industries Marine Construction and Design Company. Site operations focused initially on the construction of commercial fishing vessels, and later (in the 1980's) on naval ship repair.

Site operations were discontinued in the 1990's, and most of the shipyard facilities were demolished in 2000, except for a set of abandoned shipway ramps and marine railways extending bayward from shore near the middle of the site (Figure 2). The features that remained at the start of design – a shoreline seawall (Figure 3) and a set of abandoned shipways (Figure 4) – dated back to the earlier part of the 20th century.

Figure 1. Site location in San Diego Bay.

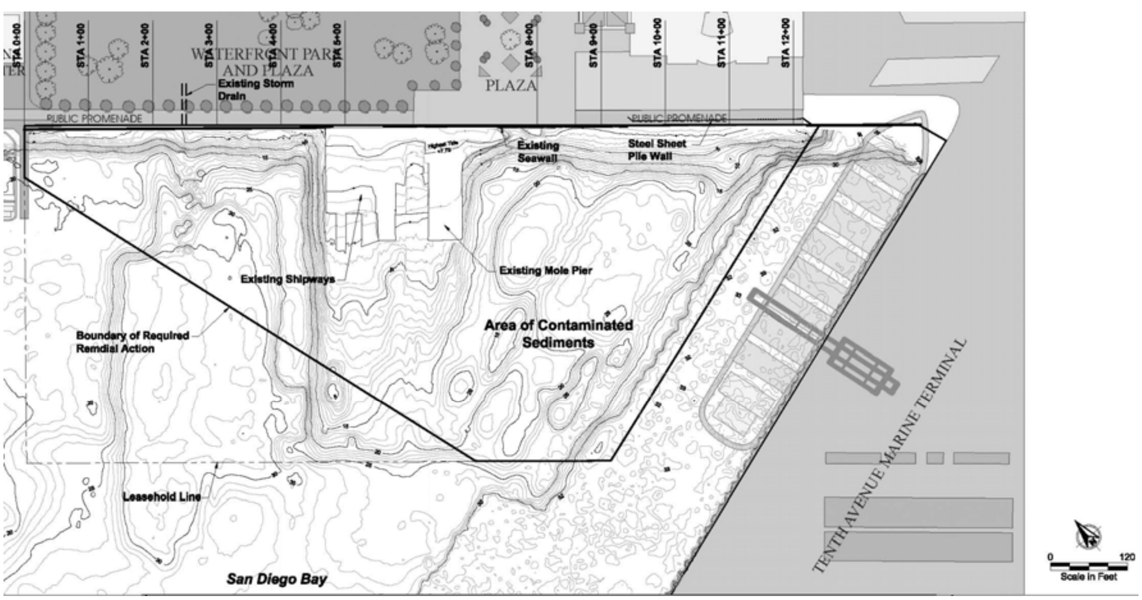

Figure 2. Map of site showing pre-existing conditions and bathymetry.

Figure 3. Campbell Shipyard project site before construction – seawall (right foreground) and south mole pier (center).

Figure 4. Abandoned shipways area, showing mole pier (left) and marine railway (center).

Site Cleanup Requirements

In 1995 the California State Regional Water Quality Control Board (RWQCB) issued Cleanup and Abatement Order (CAO) 95-21 to Campbell Industries to initiate cleanup of upland soils, groundwater and sediments at the site, due to the presence of metals (copper, zinc and lead), petroleum hydrocarbons, PAHs, PCBs and TBT. The Port took over cleanup responsibilities from Campbell Industries and completed remediation of soil and groundwater in upland areas in 2001. This action was also intended to provide source control from any remaining contaminated soils or groundwater to the aquatic environment; the next step in the remedial process was to perform cleanup of contaminated sediments in the offshore aquatic areas. The project described in this paper – cleanup of contaminated sediments – involved sediment remediation over an area of approximately 3.7 hectares (9.2 acres), extending along about 366 linear meters (1,200 linear feet) of shoreline.

Selection of Cleanup Alternative

The Port evaluated various alternatives to select a cost-effective cleanup solution that met the objectives of the CAO (e.g., clean up the site to a level that meets CAO-specified chemical concentrations), considered existing and planned adjacent site uses (vessel traffic at TAMT and public boating), and was as consistent as practicable with identified goals among stakeholders (e.g., environmental groups, adjacent tenants, and landowners).

The key alternatives that were considered included dredging all of the contaminated sediments, and disposing of those sediments at an upland facility; isolating all contaminated sediments by capping; and various combinations of the two. Each alternative also needed to incorporate some form of on-site mitigation for habitat losses; this resulted in the inclusion of a raised "eelgrass habitat area" in the area previously occupied by the abandoned shipways. This feature and its design are discussed later in the paper.

The alternative of dredging all contaminated sediments from the site was determined to be infeasible and cost-prohibitive due to the significant and highly variable vertical and horizontal extents of the contaminants, the likelihood of impacts to existing structures, and the requirement to provide substantial habitat mitigation. The Port selected an engineered capping alternative with targeted dredging as the preferred alternative for design, because it had the following advantages:

- It met RWQCB CAO cleanup requirements by providing a clean substrate over contaminated sediments, isolating the sediments from human and ecological receptors and meeting the required surface sediment concentrations.
- It incorporated a 1.6-acre eelgrass habitat area, meeting habitat mitigation goals, and did so by taking advantage of existing site topography (i.e., the shipway ramps).
- It provided sufficient water depths to accommodate traffic to and from the adjacent TAMT facility, as well as current and projected recreational and commercial boating activities in the vicinity, consistent with current and anticipated future site use.
- It was determined to be the most cost-effective solution that met stakeholder needs.

Figure 5 illustrates the layout of the selected cleanup remedy.

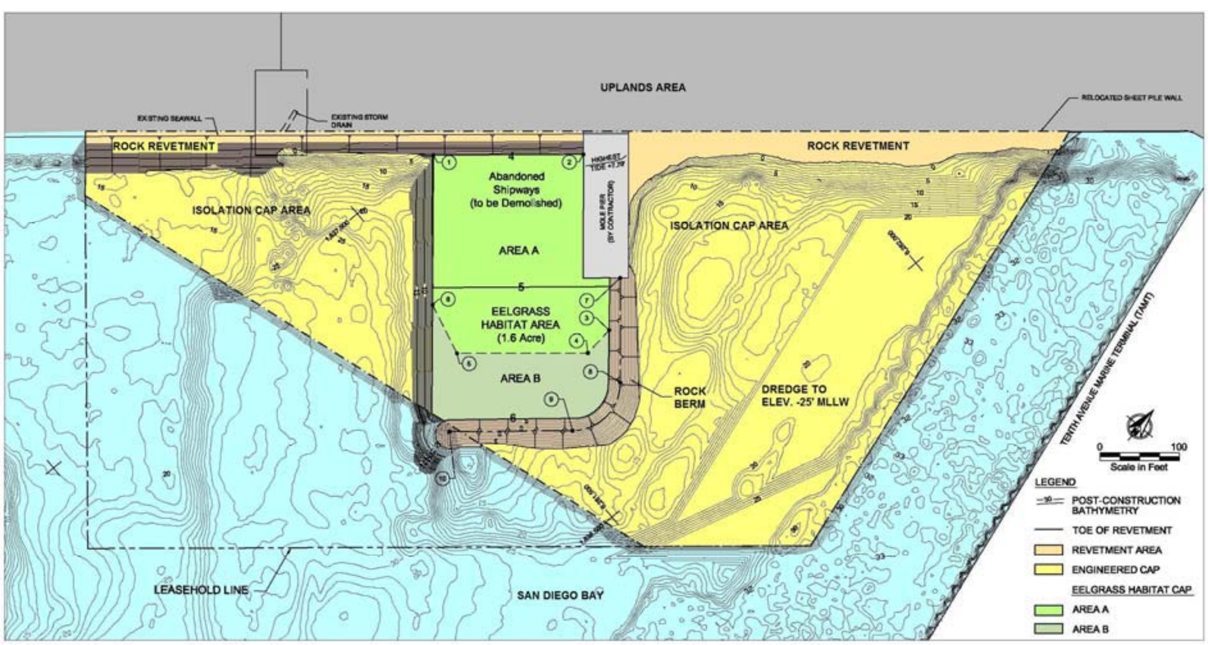

Figure 5. Map of Campbell Shipyard project site, extent of sediment cleanup and key project features.

Design Team and General Design Approach

The Port of San Diego used a team of six consultants for project design. Each firm contributed a key area of technical expertise to the project, including remedial design and civil engineering (Anchor Environmental), hydrodynamic studies (Everest International Consultants), habitat design and mitigation (Merkel and Associates), structural engineering (Blaylock Engineering Group), geotechnical engineering (TerraCosta Consulting Group), and waste characterization and disposal (Ninyo & Moore).

The overall design philosophy was to use prescriptive (method-based) specifications only where necessary, and to instead use performance-based specifications to allow the contractor flexibility to develop their own construction methods, subject to certain limitations, wherever possible. In that manner, the project could take advantage of the contractor's own special knowledge and equipment, and to avoid specifying one approach when a different, more cost-effective and acceptable method could potentially be proposed by the contractor. In some cases, however, critical items needed to be specified in a prescriptive fashion in order to avoid potential uncertainties or complications.

DREDGING DESIGN

Although capping was the selected remedial alternative for the site, placing cap materials directly on top of the existing mudline would raise the existing bathymetry, which in turn might conflict with project and stakeholder requirements in some areas of the site. As a result, the design team incorporated areas of dredging into the project, as a precursor to capping, in the following locations:

- Open water areas adjacent to the neighboring TAMT needed to maintain navigational depth requirements of -6.1 to -7.9 meter (-20 to -26 feet) Mean Lower Low Water (MLLW), to accommodate container ships and fruit-hauling vessels calling on the facility at regularly scheduled intervals. Therefore, the area adjacent to TAMT needed to be dredged to elevations -7.6 and -9.5 meter (-25 and -31 feet) MLLW prior to capping, to allow sufficient clearance after the 5-foot-thick engineered cap was placed. The dredge volume for this area was estimated to be approximately 9,175 cubic meters (12,000 cubic yards (cy)).
- The shipway ramps needed to be lowered to an elevation suitable for constructing the eelgrass habitat area. The concrete ramp surfaces, which initially started at an elevation equal to the adjacent land and ramped down, needed to be demolished and removed, along with the steel rails and other miscellaneous debris; and the underlying sediments dredged, until elevations ranging from -2.1 to -2.7 meter (-7 to -9 feet) MLLW were reached. This would allow the post-cap surface to be at the shallow subtidal elevations -1.2 to -1.8 meter (-4 to -6 feet) MLLW, targeted for eelgrass development. The dredge volume for this area was estimated to be approximately 12,234 m^3 (16,000 cy).
- Isolated areas of elevated bathymetry were identified for dredging, in order to create a more consistent and level site bathymetry, and to eliminate large-scale topographic features that could interfere with the capping process.
- An additional 1,759 cubic meters (2,300 cubic yards) of debris removal and dredging was needed along the seawall to allow for placement of a stabilizing rock revetment, as discussed later in this paper.

All of the dredged material exceeded CAO cleanup criteria, but was not characterized as hazardous waste. Sediment characterization testing for bulk chemistry and leachability indicated that the material would be chemically acceptable for disposal at local San Diego County landfills run by Allied Waste – including the Otay and Sycamore landfills. These landfills require that the sediment have a water content low enough to meet the "paint filter" test.

Mechanical dredging was required for this site, since hydraulic dredging was determined to be impracticable due to lack of upland space for either active or passive dewatering of hydraulic slurry. A 0.3-meter (1-foot) overdredge allowance was specified to account for equipment tolerances. Payment for dredging was based on the in-situ volume dredged, as measured by pre- and post-dredging bathymetric surveys, and was inclusive of all rehandling, dewatering, stockpiling, transport, and disposal costs. This payment approach was used instead of paying per tonnage generated, in order to avoid any payment issues related to the water content (and therefore weight) of the generated sediment.

Performance-based specifications were utilized for sediment management, stockpiling, dewatering and transportation, to allow the Contractor flexibility in their methods, within specified limits and requirements. One example was that permits allowed sediments stockpiled on barges to drain directly back into Bay receiving waters, provided that no sediment escaped with the water off the barge, and provided that water quality requirements were met at all times. The specifications described the performance measures the Contractor was required to meet (e.g., water quality criteria, filtering of solids on the barge) but did not prescribe the exact method to be used to meet these performance requirements. The methods for dewatering the sediment to meet landfill water content requirements were also left to the Contractor.

Debris

Debris surveys using side-scan sonar and diver observations indicated the presence of timber piles, concrete and metal debris, rocks and other features in many areas of the site. The specifications required removing certain debris items that protruded significantly above the mudline and could therefore interfere with the capping process or with the performance of the cap. In areas to be dredged, the contractor was advised that additional, previously unidentified debris could be present, and would have to be removed as well, on a unit-cost basis. Beyond the dredging areas, in areas to be capped only, the Contractor was required to remove only those items identified in the plans rather than doing a site-wide cleanup pass, to avoid cost over-runs from “chasing” debris unnecessarily. All removed debris was to be stockpiled separately from sediment, and paid for on a per ton basis.

DESIGN OF SEDIMENT ISOLATION CAP

Design analyses were conducted to select appropriate material types and thicknesses for the cap, in order to ensure that the engineered cap will effectively isolate the contaminants and limit contaminant mobility through the cap materials, under both short- and long-term scenarios.

The sediment cap design was consistent with current regulatory guidance for sediment capping: U.S. Environmental Protection Agency’s (EPA’s) “Guidance for In-Situ Capping of Contaminated Sediments” (EPA 1998), published as part of the agency’s Assessment and Remediation of Contaminated Sediments (ARCS) program; and Technical Report DOER-1 by the U.S. Army Corps of Engineers Waterways Experiment Station, entitled “Guidance for Subaqueous Dredged Material Capping” (USACE 1998).

The performance endpoint for contaminant isolation selected for this project was a comparison of predicted porewater concentrations to applicable surface water quality criteria, in the top 1 centimeter of the cap (the biologically active zone) at 100 years after construction. The water quality criteria selected were the California Ocean Plan’s 6-month averages for metals, and ecological screening values from the Department of Energy (1999) for organic compounds. The upper-1-centimeter performance endpoint was significantly conservative because it did not account for the rapid dilution of porewater that occurs as it enters surface waters, where surface water criteria normally apply.

Modeling of Cap Chemical Isolation

Migration of chemically impacted porewater through the cap was modeled using a revised version of the Boudreau model (Boudreau 1997), to determine the probability of contaminant breakthrough at concentrations greater than the water quality criteria, over a period of 100 years. The model was run for the site’s most prominent contaminants (i.e., copper, lead, zinc, pyrene and fluoranthene) and assumed physical and hydraulic properties of an aquatically-placed sand and using partitioning coefficients obtained from site-specific studies and other literature. All modeling values were purposely chosen to be conservative to reflect uncertainties inherent in the modeling effort. As a key example, the source of contaminants from underlying sediment was conservatively assumed to be infinite.

Water quality concentrations were predicted to be well below the water quality criteria after a 100-year period for a 0.61 cm (2 feet) thick isolation capping layer. The isolating portion of the cap was therefore planned to be a 0.61 meter (2 feet) minimum thickness of fine to medium sand. A 15.2 cm (6 inch) overplacement allowance was included for equipment tolerances.

Cap Placement Design

The cap was going to be constructed over very soft and loose, unconsolidated sediments with undrained strengths ranging from only 48.8 to 488 kilograms per square meter (10 to 100 pounds per square-foot). The low strength of the seafloor sediments posed a design challenge both for the construction process and for the cap’s long-term stability. First, the sediments would be susceptible to bearing capacity failures if cap material were placed on it too quickly or too abruptly; second, in the long run they would be susceptible to movement and lateral spreading in a seismic event. These possible effects were especially pronounced on slopes and around the cap edges. The potential for subgrade instability was addressed by carefully specifying the cap construction approach, and by including two measures by which the subgrade was physically stabilized.

Cap Placement Methods

Potential bearing capacity concerns for unconsolidated sediments were addressed by requiring that the Contractor build the cap layers in individual lifts. By controlling the maximum cap lift thickness during construction, the differential fill thickness during placement would be restricted so as to reduce the potential for bearing capacity failure. Another design element addressing this issue was a gently sloping edge detail for the edge of the cap, to lessen the abruptness of the transition between fully constructed cap layers and the unloaded area immediately beyond the cap edge.

Physical Stabilization of Subgrade

In addition to these specified construction methods, the design also incorporated rock placed directly into the soft sediments at strategic locations (predominantly slopes and cap edges, and areas where the soft sediments were thickest), to further strengthen the subgrade before construction, and to improve the sediments' ability to withstand seismic loading without spreading out. This "foundation rock" was to be applied directly onto the exposed sediments at a specified tonnage per unit area, in the expectation that it would sink into the soft layer of sediments at each location, and thus effectively strengthen the sediment layer. The required tonnage was determined based on the softness and thickness of the unconsolidated sediment at each location of foundation rock placement.

The Port added another measure of protection into the project, in the form of a layer of geotextile fabric to be laid down over the seabed prior to starting installation of the sediment cap. This geotextile layer also allowed an increase in the allowable thickness of individually placed cap lifts (from 15.2 cm (6 inches) maximum, to 30.5 cm (12 inches) maximum), potentially speeding up the construction process. Furthermore, the geotextile provided a marker layer between the cap material and the underlying sediment, facilitating later quality control and inspection during cap installation.

Beneficial Reuse Source for Base Cap Material

Modeling of the cap's chemical isolation properties (discussed previously) indicated that 0.62 meter (2 feet) of fine to medium sand would be sufficient for capping purposes. This afforded the Port an opportunity to beneficially reuse materials that were already planned for excavation from a separately planned project on San Diego Bay. Grand Caribe Island, located in the Coronado Cays residential and marina development just south of the City of Coronado, was planned for excavation by the Port to form an intertidal wetlands area. The timing for that project was anticipated as slightly later than the timeframe for the Campbell work. Furthermore, material sampling and characterization from Grand Caribe Island showed the sand material to be physically suitable as base cap material, and sufficiently free of chemical constituents for use in the cap. As a result, it was decided to make the Grand Caribe Island site the required source of base cap material for the project. In so doing, the Port saved the costs of the previously planned disposal of the excavated material, as well as the costs of importing clean sand for the Campbell remediation project.

Design of Surficial Cap Protection

Because of the proximity of the TAMT to the capping area, potential erosion from propeller-wash currents was a key consideration in designing the Campbell Shipyard cap. Other possible sources of erosive forces included propeller wash forces from other recreational vessels and ferries operating in the vicinity of the site, wind waves and tidal currents. Vessels calling at TAMT were determined to be the biggest influence, and thus were used as the basis for design of cap protection.

A hydrodynamic analysis was conducted to determine the size and thickness of armor rock and filter layer that would be needed to protect the 0.61 meter (2 feet) thick sand isolation cap. A probabilistic approach was adopted, based on the statistical properties of tug boat operations and reoccurrence of various tidal elevations at the project site.

Modeling of Propeller-Wash Forces

Propeller wash forces were modeled using the PROPWASH model (Blaauw and van de Kaa 1978, Blaauw et al. 1984, and Verhey 1983). The model predicts the velocity field behind a propeller jet; a representative output of this model, as applied to a theoretical tugboat operating at TAMT, is shown on Figure 6.

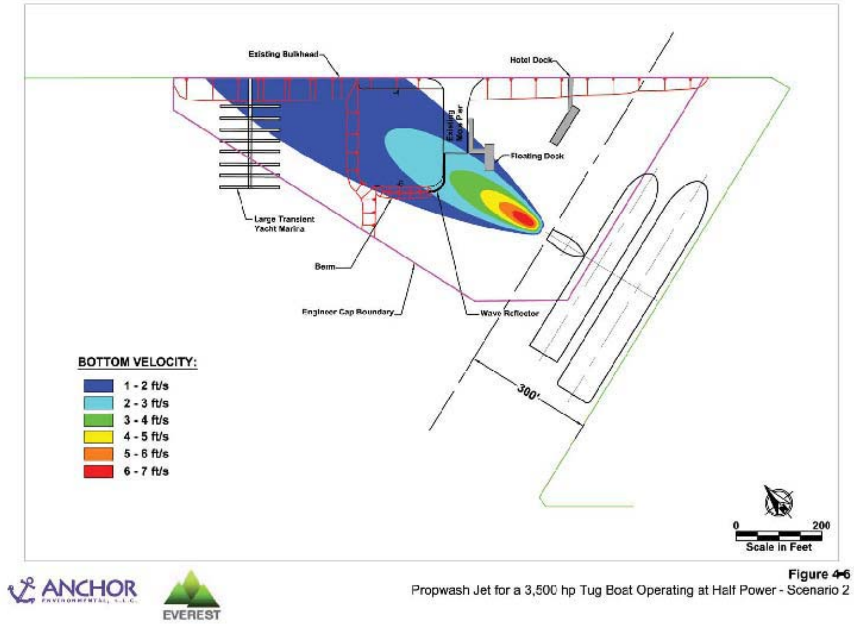

Figure 6. Propeller-generated jets as modeled for Campbell Shipyard site.

Initial input parameters for the model were developed using existing knowledge of the site, and were then through a field program conducted in February 2003 at the project site to collect site specific propeller wash data. A SonTek Acoustic Doppler Current Profiler (ADCP) mounted along the side of a survey vessel was used to measure the tug-boat generated currents along different transects run behind the tug boat. When comparing the measured tug-boat-generated velocities with the PROPWASH model-predicted velocities, the field measured velocities were generally higher than those predicted by the numerical PROPWASH model. Hence, the empirical parameters in the PROPWASH model were adjusted until there was better correlation between the model-predicted and field measured velocities.

Probabilistic Analysis of Erosional Forces

Projected operations of container and breakbulk vessel traffic at TAMT were estimated based on discussions with Port wharfingers. Based on these discussions it was estimated that on average, tug boats would be operating at TAMT (during vessel ingress and egress events) for about 2.8 percent of the time throughout a year. Typically there would be only one ship in berth, but there were also expected occasions when a second ship would pull into berth, and would have to pass around the first – these would impose the most significant propeller wash forces on the cap area.

Probability distributions were defined for high vs. midrange settings on tugboat motors and for tidal elevations, since propeller wash forces would extend out over a greater distance at higher tides, when water depths were greater.

These data were used to construct a probability of occurrence of maximum bottom velocity on an annual basis (Figure 7). The most commonly occurring maximum bottom velocity was on the order of 1.2 to 1.5 meters per second (4 to 5 feet-per-second (fps)), and the maximum overall bottom velocity (no projected chance of exceedance) was 2.8 m/s (9.2 fps).

Given this probability distribution, a design-level velocity needed to be defined and an appropriate armor rock size selected. An important factor in this decision process was the fact that erosive events would have a very short duration, during which some rearrangement of surface armoring material could be expected. In other words, erosion-induced “damage” to the armor layer would not amount to an actual breaching of the cap, but rather would consist of a modest repositioning or shifting. For this reason, a one percent chance of velocity exceedance was selected as a reasonable criterion for armoring design. This translated into a maximum design velocity of 1.77 m/s (5.82 fps).

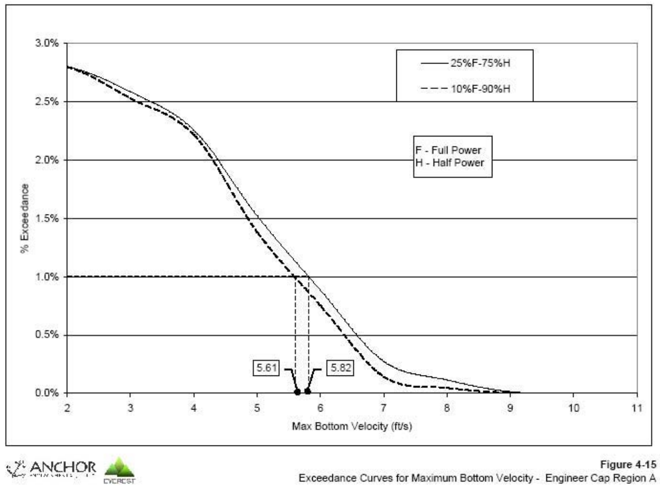

Figure 7. Probability distribution of propeller-wash velocity incidence on cap area.

Selection of Armor Rock and Layer Thickness

Using this design velocity, armor layer thickness and rock size was determined based on guidance from EPA (1998) and USACE (1998). The result was a uniform 0.61 meter (2-foot) thick layer of armor rock with a median diameter of 0.3 meter (1 foot), throughout the capping area. The armor rock would be placed over a filter layer of gravel material.

Final Cap Design

Figure 8 summarizes the final selected cap design for the overall site.

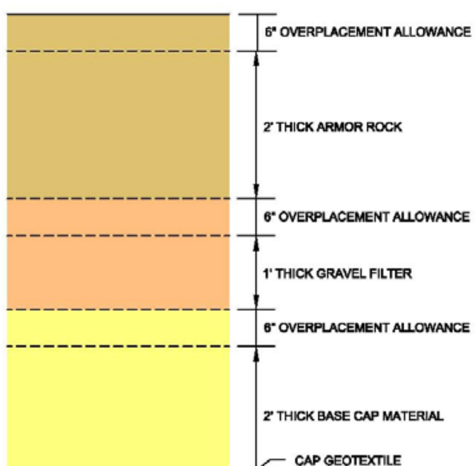

Figure 8. Summary cap design for sediment isolation cap.

MITIGATION CONSTRUCTION OF EELGRASS HABITAT AREA

Another key objective of the project was to replace ecological habitat lost due to implementation of remedial actions. Habitat creation to mitigate for lost habitat is preferred to occur on-site, which was feasible for this project. Mitigation for the loss of approximately 1 acre of existing eelgrass was negotiated as requiring the construction of approximately 1.6 acres of protected eelgrass habitat area. This was most cost-effectively incorporated into the project design by taking advantage of existing bathymetry: the habitat area was located in the existing elevated area of the shipyard ramps (refer to Figures 2 and 5).

The optimal elevation range for eelgrass colonization was shallow subtidal depths, so the final design surface elevation for the eelgrass habitat area was selected to be between elevations -1.2 and 1.8 m (-4 and -6 feet) MLLW. This portion of the site would be capped with sandy material to provide a clean substrate for benthic organisms to recolonize, while the flatter topography of this habitat "plateau" would facilitate invertebrate colonization and fish utilization. In order to achieve these target elevations, the design included demolition of the nearshore portion of the abandoned shipway ramps, and removal of underlying contaminated sediments, to elevations that would support the placement of clean fill to the eelgrass habitat area target elevations.

Consistent with the rest of the site, the eelgrass habitat area needed to be capped by a 2-foot-thick sand cap isolation layer. Above this isolation layer, it was not feasible to place armor rock, since that would not allow eelgrass growth. Instead, a specifically designated "habitat cap" material was specified for the upper surface in the habitat area, with a gradation that was optimized for eelgrass germination and growth (this amounted to a fine sandy material between 0.1- and 0.6-millimeter average grain size). This material was too fine to resist any significant erosional currents, so the eelgrass habitat area needed to be protected by means other than surface armoring.

Protecting the eelgrass habitat area was accomplished by two design features:

- The southern and western (bayward) sides of the eelgrass area were bordered by barriers to propeller wash currents from the TAMT area. The existing mole pier (on the south side of the habitat area) and a designed rock berm (on the southern and western sides) served this purpose (see Figure 2). Hydrodynamic analyses of propeller wash currents, similar to those used for designing the armor rock, were used to verify that the rock berm would effectively shield the eelgrass area from propeller wash, and to select the berm's top elevation (+0.3 m (+1 ft) MLLW). The existing mole pier, having fallen into a state of disrepair in recent years, required retrofitting and stabilization so that it could be used as a permanent site feature.
- A buried layer of filter gravel was incorporated into portions of the habitat cap, below the surface, to act as a "back-up" erosion-resistant layer in the event that the surficial eelgrass cover and habitat cap material were stripped off by high current forces. The gravel layer was included only in the westernmost areas of the habitat cap, since hydrodynamic analyses indicated that was where the greatest potential for erosive forces would be.

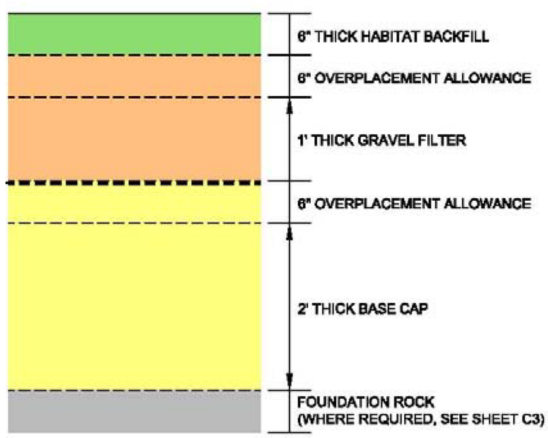

Figure 9. Summary of cap design for eelgrass habitat area.

In addition to the eelgrass habitat area, the project incorporated additional artificial fish reefs as a compensatory action to the loss of intertidal habitat. These reefs were to be constructed predominantly of 61 cm (24-inch) and 122 cm (48-inch) Armortec A-Jacks® units, which increase structural relief along the wave berm slopes, and thereby provide functional benefits to fish and invertebrate communities within the Bay.

SEAWALL STABILIZATION

A concrete and timber seawall constructed in the mid-1920s is located along the property. Along most of its length, its pre-existing condition was poor (Figure 10). Geotechnical and seismic studies indicated that the wall is seismically unstable, and that it would likely fail under a design-level earthquake (10 percent chance of exceedance in 50 years). Since this would damage portions of the sediment cap near the base of the wall, the seawall needed to be stabilized and repaired.

A rock revetment was designed to be constructed along the exposed front of the seawall, to provide lateral stability in the event of an earthquake. The revetment was designed as a sloping mass of quarter-ton rocks, placed to reach a top elevation of 1.5 meter (5 feet) MLLW and a 2H:1V sloping geometry. The revetment rock would overlie the 0.61 meter (2-foot) isolation cap sand layer (with a foot-thick layer of filter gravel separating the rock from the underlying sand).

Figure 10. Typical portion of existing seawall in need of repair.

The specifications were written to require the contractor to place an initial lift of 0.3 meter (1 foot) of revetment rock along the entire length of the seawall before placing the remaining thickness of material. This was intended to avoid negative consequences of differential loading on top of the underlying cap layers.

CAP MONITORING

To ensure continuing performance of the constructed cap, a long-term monitoring plan was developed for the site, in consultation with regulatory agencies.

The proposed long-term monitoring program included monitoring of the following aspects of the project:

- Monitoring of the cap's physical condition, to discern whether any physical degradation and/or erosion is occurring.
- Monitoring of porewater at the top of the isolation cap layer, to see if site contaminants are being successfully contained below the cap.
- Monitoring of eelgrass recolonization of the eelgrass habitat area.
- Event-related monitoring, as needed to address significant, one-time occurrences (e.g., large earthquakes).

CONSTRUCTION SEQUENCING

For some elements of the project, the sequencing of actions was of great importance. In these cases, the exact sequence of work was specified. For other, less critical action items, the contractor was given the responsibility of developing a construction sequence. Significant items for which the specifications called out sequencing were as follows:

- The existing, dilapidated mole pier needed to be repaired and retrofit before dredging the shipways area, because dredging along the side of the existing mole pier would possibly destabilize the structure.
- All required demolition and debris removal needed to be completed before dredging, so that payment for demolition and debris removal (tonnage trucked off site) could be tracked separately from payment for dredging (per cubic yardage, as determined from pre- and post-dredge surveys). The pre-dredge survey would immediately follow completion of demolition and debris removal.
- All dredging at the site needed to be fully completed and approved before starting any capping activity. The purpose of this requirement was to avoid possible recontamination of the cap by resuspended dredged sediments. Similarly, all placement of foundation rock into the soft subgrade needed to be done before placement of any cap materials.
- A pilot cap section needed to be completed and fully approved (layer-by-layer) to demonstrate that the Contractor's techniques were successful, before capping of the rest of the site could begin.
- The sequence of cap placement was strictly defined (foundation rock, cap geotextile, sand base cap, gravel filter layer, and surficial armor rock), and each layer needed to be approved before the next layer could be placed.
- After placing sand cap material in any portion of the site, the contractor was cautioned to install the overlying filter gravel and armor rock as soon as possible, so as to minimize the period of time during which the sand layer was exposed and susceptible to erosion by propeller wash or other forces. The Contractor was allowed to subdivide the capping area into separate units of manageable size, each of which would be capped separately, in order to meet this requirement.
- The operation schedule at TAMT was identified to inform the contractor about on-going vessel navigation and berthing operations at TAMT.
- TAMT agreed to perform line-hauling of their berthing vessels for a four-month period, in order to facilitate the completion of dredging and capping in the vicinity of TAMT.

CONCLUSIONS

The Campbell Shipyard Sediment Remediation project involved a variety of interdependent aquatic design tasks, covering a wide range of technical disciplines, including dredging, capping, structural rehabilitation and habitat re-establishment. The project was located in an active industrial area, posing constructability challenges. Furthermore, it involved numerous stakeholders, so the Port's design team had to design the project to meet their multiple (and sometimes conflicting) concerns - while ensuring that the cleanup goals for the site were fully met. Altogether this required developing a very site-specific, and uniquely tailored, remedial design.

Design of the project involved the careful use of performance-based specifications wherever there was potential flexibility with respect to the contractor's methods. In these cases, the use of performance specifications attempted to take advantage of the contractor's ability to develop cost-effective solutions. It was essential that the specifications clearly lay out the basis for acceptance in cases where methods were left to the contractor's discretion.

Owing to the large number of individual construction tasks required for the project, the design documents laid out a fairly comprehensive construction sequence, including required precursor steps where necessary.

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