Design and Construction of a Nearshore Confined Disposal Facility

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Abstract

The use of confined disposal facilities (CDF) is becoming a more often selected option for the disposal of contaminated dredged material. The primary objective of a nearshore CDF is to contain dredged material in an environmentally protective manner. In addition, many CDFs have another objective, or generally beneficial side effect, which is to facilitate future use of the upland property created by the construction of the facility. These future uses can range from habitat enhancement, to public open space, to port facilities and other water-dependent uses.

The design of a CDF involves several aspects of engineering and science including subsurface investigation, containment structure design, chemical fate and transport (including groundwater modeling), construction considerations, and in some cases, habitat mitigation/restoration considerations. This paper presents a generalized approach for the design and construction of a nearshore CDF to contain contaminated dredged sediments. Two project examples are presented to illustrate the complexity of such a design.

Introduction

In September of 1983, the U.S. Environmental Protection Agency (EPA) listed the Commencement Bay Nearshore/Tide Flats (CB/NT) on the National Priority List (NPL). Since that time, extensive remedial design efforts have been undertaken by the respective Potentially Responsible Parties (PRPs) on several of the industrial waterways within the bay, with oversight provided by EPA Region 10. Hart Crowser and Berger/ABAM Engineers have recently completed the final remedial design for two of these waterways including the Thea Foss and Wheeler-Osgood Waterways and the Hylebos Waterway Remediation Projects.

The Thea Foss and Wheeler-Osgood Waterways Remediation Project, under direction of the City of Tacoma, involves the dredging and disposal of more than 380,000 cubic meters (m^3) in a CDF constructed in the St. Paul Waterway, the site of a working timber mill and sawmill (Figure 1). Three separate earthen berms will be constructed for habitat and sediment containment purposes. Remedial construction of the St. Paul CDF began in the fall of 2003 and is expected to be completed in early 2005.

The Hylebos Waterway Remediation Project, directed by Glenn Springs Holdings, Inc., with support by the Port of Tacoma (Port), includes the dredging of approximately 230,000 m^3 of contaminated sediments from the Hylebos Waterway. Disposal of the dredged sediments will be within a CDF constructed at an old waterway slip (Slip 1) owned by the Port located adjacent to the Blair Waterway in Commencement Bay. Construction of the large sand and gravel/riprap containment berm for the CDF required a staged approach with overexcavation and replacement of soft, compressible foundation soils. Following placement of the contaminated dredged material within the Slip 1 CDF, a thick cap of clean import materials and asphalt pavement will cover the area to support a future container terminal facility within one year of fill placement. Remedial construction began in the fall of 2002 and is expected to be completed in early 2005.

Confined Disposal Facility Design

This section discusses some of the major considerations for designing a CDF with specific examples provided from the Slip 1 and St. Paul CDFs.

CDF Siting

The initial siting of a proposed CDF will dictate the configuration of necessary containment structures (e.g., earthen berms, sheet pile walls, etc.) to create the facility. Selection of the appropriate type of structure(s) may depend on a number of factors including available space, availability of materials, and equipment restrictions during construction. As discussed further below, the presence of existing facilities or operations adjacent to the location of the proposed CDF may limit the configuration or impose additional design considerations.

For the Thea Foss Project, the existing 11-acre St. Paul Waterway, was selected as the site of the CDF and an earthen berm was designed to close off the waterway from the adjacent Commencement Bay (Figure 1). Similarly for the Hylebos Project, an earthen berm was designed to enclose an existing ship and barge slip (Slip 1) in the Blair Waterway (Figure 1). The remainder of this section presents design considerations for a CDF with earthen containment berms.

Subsurface Geotechnical Investigation

Following siting of the CDF, a thorough subsurface geotechnical investigation must be completed focusing on the identification of any compressible soils within the foundation soils, particularly focusing on the area beneath the footprint of the proposed berm. Compressible soils beneath an earthen berm may lead to short- and/or long-term instability of the berm, if not designed properly.

Slope Stability Analysis Methods for Containment Structure Design

In addition to the considerations regarding the siting of the CDF, the nature of the foundation soils may also be a factor in the selection and design of the containment berms. Slope stability analyses, which can be performed using commercially available computer software packages, such as SLOPE/W, should be completed as part of the design. Stability analyses require the shear strength of the sediment, which are unique to the loading and drainage conditions being analyzed, as described below.

- **"Undrained" Strength.** During berm construction as loads are applied, any underlying cohesive layers (i.e., silt and/or clay), which have a significantly low permeability, will likely have a reduced strength in the short-term due to the build-up of excess pore pressures. Therefore, the "undrained" strength of the cohesive layer is applicable to the short-term condition.
- **"Drained" Strength.** Following berm construction, underlying sand layers, which are relatively permeable, will immediately achieve their full shear strength. For this reason, "drained" strengths should be applied to free-draining (i.e., sand) layers in the stability analysis for both the short- and long-term conditions. Drained strength parameters should also be applied to any cohesive layers when evaluating the long-term slope stability, after the cohesive soils have had sufficient time to dissipate excess pore pressures and consolidate.
- **"Residual" Strength.** If a soil becomes liquefied in an earthquake, the shear strength is reduced from the generation of excess pore pressures, which is referred to as the post-liquefaction residual shear strength. As part of the seismic stability analysis, residual shear strengths should be used for potentially liquefiable soils.

Stability under Static Conditions. Slope stability should be evaluated for both the short- and long-term static conditions using the undrained and drained shear strengths, where appropriate. During the Slip 1 CDF design, a layer of soft compressible silt up to 12 meters thick was identified during the subsurface investigation, which proved to be problematic for short-term static stability of the berm. Analyses indicated that the berm could not be constructed to its full height without exceeding the short-term bearing capacity of the underlying silt. Therefore, a staged approach was adopted, such that the soft foundation soils would have sufficient time to gain strength under the first stage of the berm prior to constructing the second stage. In addition, an overexcavated "keyway" and temporary buttress were also designed and constructed from select import materials to provide stability during the construction, as shown on Figure 2.

Stability under Seismic Conditions. In addition to static stability, containment berm design should include evaluation of seismic stability, if applicable based on the geographic region. Earthquake conditions should be modeled using both pseudo-static and residual strength analysis techniques. Pseudo-static analyses are representative of the conditions during shaking, and residual strength analyses are representative of conditions immediately following shaking. In a residual strength analysis, the slope should be analyzed under static conditions using the residual strength of the potentially liquefied soils, as discussed below.

As part of the Thea Foss and Hylebos Projects, the containment berms were designed for two separate design-level earthquakes. A ProShake analysis was performed to determine site-specific seismic response parameters for the two design-level events:

- Operating Level Event (OLE). This is defined as a seismic event with a return interval of approximately 72 years (50 percent chance of exceedance in 50 years). Port facilities are typically designed to remain operational after an OLE.
- Contingency Level Event (CLE). This is defined as a seismic event with a return interval of approximately 475 years (10 percent chance of exceedance in 50 years). Port facilities might undergo nominal damage in a CLE, but should not suffer irreparable damage or structural collapse. In the case of the CDF berms, significant deformation may occur, but complete berm failure and release of contaminated dredged sediments would not occur.

The **potential for liquefaction**, which can lead to loss in soil strength, is an important consideration in the seismic stability evaluation. Liquefaction is a phenomenon whereby excess pore pressures are generated within the soil due to ground shaking during an earthquake. Liquefaction potential can be evaluated using empirical correlations to Standard Penetration Test (SPT) blow counts (Seed et al. 1985 and NCEER 1996).

Seismic deformation analyses should be completed to evaluate the possible magnitude of ground movement and potential for release of contaminated sediments resulting from a design level seismic event. Two types of deformation analyses can be used to evaluate the seismic performance of a containment berm including a finite element analysis and a Bartlett and Youd lateral spreading analysis (Youd et al. 2002). Figure 3 presents the results of a finite element analysis using the computer software Plaxis for the Slip 1 CDF berm, showing deformation of the berm centerline on the order of 1.5 meters (5 feet) when subject to the CLE earthquake.

Erosion Evaluation

Depending on the location of the CDF and site conditions, appropriate erosion protection for the containment berm may be necessary. Considerable forces may be imposed on the CDF containment berms by a number of common processes including wind-generated waves, currents and tidal fluctuations, passing vessel wakes (including surface waves and deep-draft pressure waves), propeller-induced scour, ice gouge, and anchor drag.

Some of these erosive forces can be controlled through operational restrictions (i.e., vessel speed limits, no anchor zones, etc.), but consideration of natural wave forces and currents must be accounted for in the design. Computer models, such as the Automated Coastal Engineering Software (ACES), are available to aid in the analysis of wave impacts during design.

Construction Considerations

Appropriate construction materials must be selected to construct a CDF containment berm. Material selection may be based on a number of factors including the results of the slope stability analysis, erosion evaluation, the availability of materials from local sources, groundwater and chemical transport modeling, and constructability considerations.

Project experience with subaqueous embankment construction has shown that training terraces are required during construction to achieve the target slopes in the range of 2H:1V. Training terraces typically consist of two parallel rows of riprap that are placed along both sides of the berm and then select import materials are placed between them creating a single lift. Subsequent lifts are constructed in the same fashion. The riprap that comprises the training terraces remains in place on the face of the berm and may serve as an armoring layer against erosion and scour.

Groundwater and Chemical Transport Modeling

Groundwater Modeling

Groundwater modeling provides an estimate of the post-construction groundwater elevation within the CDF, which is the basis for the contaminated sediment ‘fill height’. Contaminated sediments that are kept in anaerobic conditions are generally less likely to mobilize and be transported from the CDF via groundwater. Hydrogeologic modeling should be performed for the long-term condition of a completed CDF, including the berms and overlying cap. Monitoring wells can be installed adjacent to the proposed facility to collect data on the regional groundwater flow conditions. The USGS Modular Three-Dimensional Groundwater Flow Model (MODFLOW), a finite-difference groundwater flow model, was used to predict groundwater conditions for the two case examples presented herein using site-specific inputs. MODFLOW also provides the primary groundwater transport pathway direction within the CDF.

Chemical Transport Modeling

Chemical fate and transport modeling, based on groundwater flow modeling and leaching test results, should be performed to predict chemical concentrations and potential transport via groundwater flow out of the CDF during the long-term leaching of chemicals from the confined sediment. The Pancake Column Leach Test (PCLT), developed by the U.S. Army Corps of Engineers (Corps) and formerly known as the Thin-layer Column Leach Test (TCLT), should be performed on a composite sample(s) representative of the material to be confined that contains above-average chemical concentrations as compared with the overall area planned for dredging. The leaching test is conducted under anaerobic conditions to simulate the CDF environment wherein the dredged material is placed in the CDF below the predicted groundwater level. Chemicals analyzed may include metals, pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), or other constituents depending on their prevalence in the dredge prism and their range of properties indicating their mobility and persistence in the environment.

Dredged Material Disposal in a Confined Disposal Facility

Various methods are available for the placement of dredged materials within a CDF including bottom dump barge, flat deck barge, mechanical double handling over a completed berm, or pumping through a hydraulic pipeline. For each of these methods, there are CDF design considerations that may have implications during construction. Construction considerations related to consolidation settlement of the dredged sediments are discussed below.

CDF construction considerations related to disposal are dependent on the nature and characteristics of the dredged sediments and the equipment types planned for disposal. For instance, mechanically dredged sediments are typically placed directly into barges or scows and transported to the CDF, where it is most efficient to empty them by bottom-dumping or other offloading techniques within the CDF. To allow barge access to the interior of the CDF, it is often desirable to allow for a barge access channel through the berm that can be filled when the CDF nears capacity. However, the size and/or configuration of the CDF, nature of the dredged sediments, or availability of equipment may limit the feasibility of this approach. In these cases, it may be necessary to double-handle dredged material over the completed berm. The Slip 1 CDF will be filled using this method.

Hydraulic dredging, on the other hand, allows the dredged material to be pumped through a pipeline directly to the CDF, within a reasonable transport distance. Since hydraulic dredging and transport typically entrains a large volume of water with the dredged sediments, pipeline disposal may require appropriate controls, such as an overflow weir, to release the water from the CDF. Hydraulic dredging is proposed for the Thea Foss project and the St. Paul CDF will be filled via pipeline.

During disposal (bottom-dump barge or pipeline), dredged material will fall through the water column and eventually become consolidated within the CDF. The disposal process may result in a fraction of the mass to be dispersed beyond the immediate disposal area depending on the containment system.

Regardless of the method of disposal, regulatory restrictions are typically enforced to protect water quality by limiting the amount of suspended solids and/or concentration of a particular constituent released to the water column during disposal. Elutriate testing should be conducted to evaluate the potential for the release of constituents in the dissolved fraction with regard to the applicable regulatory limits. In addition, the fate and transport of the particulate fraction, which is in part dependent on the nature of the material and the method of disposal, can be predicted based on site-specific conditions using the Automated Dredging and Disposal Alternatives Modeling System ADDAMS software developed by the Corps.

The ADDAMS software was particularly useful during design of the Slip 1 CDF, where bottom-dump barge disposal of dredged sediments was planned until a point was reached when either the fill elevation prevents barge access into the slip or when water quality criteria are exceeded at the compliance boundary. At this point the second stage of the berm would be constructed, which would essentially close the CDF for direct access to incoming barges.

While the containment berm was to remain unfinished and the CDF to be open to the Blair Waterway, the potential would exist for suspended particulate matter generated during bottom-dump barge disposal to be transported out of the CDF and into Commencement Bay, potentially causing an exceedance of water quality standards established by the EPA for the project. Therefore, the short-term fate and transport of the suspended particulate matter following disposal was evaluated using the Short Term Fate of Dredged Material in Open Water module (STFATE) of the ADDAMS software package.

Consolidation Settlement of Sediments within a Confined Disposal Facility

The consolidation settlement of dredged sediments within a CDF and/or settlement of the existing foundation soils beneath and adjacent to a CDF must be considered when designing such a facility. Consolidation settlement may impact volumetric capacity of the CDF to contain dredged sediments, timing of future use of the completed CDF, and/or structures adjacent to the CDF.

Volumetric Capacity

The capacity of a CDF to contain dredged sediments will be based on the physical volume of the CDF as well as the degree of consolidation of the dredged fill and/or underlying foundation soils of the CDF. Consolidation will occur within the foundation soils and within the dredged fill materials themselves.

It is therefore important to conduct a subsurface exploration program to identify compressible foundation soils and perform geotechnical testing to evaluate the magnitude and rate of potential settlement. In addition, it is important to evaluate the consolidation characteristics of the dredged fill by conducting specialized low-stress consolidation testing on a composite sample(s) representative of the dredge prism.

Using the consolidation properties of the foundation soils and the composites samples of the dredge prism, the ultimate magnitude of consolidation can be estimated using traditional methodologies. The amount of consolidation settlement should be accounted for when estimating the available capacity of the CDF. Since contaminated dredged materials are typically fine-grained with low *in situ* density, large magnitude consolidation settlement is not uncommon.

Time Rate of Settlement

Often times, an owner has future development plans for the new land to be created by a CDF, ranging from public parks to container terminal facilities, as is the case with the Slip 1 CDF. Since contaminated dredged material is typically fine-grained, the permeability is often relatively low, causing long-term consolidation. Considering the thickness of the dredged fill along with the low permeability of the sediment, it is not uncommon for primary consolidation to take more than a decade.

The time rate of that settlement can be predicted using the Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill (PSDDF) module of the ADDAMS software package. This program simulates the process of CDF filling and sediment consolidation with time. However, engineering judgment is crucial when using and interpreting the results of this type of simulation. Figure 4 presents the results of a PSDDF simulation for the Slip 1 CDF, which shows that more than 1.5 meters of settlement can be expected following the end of CDF construction.

In cases where the predicted time rate of settlement is not consistent with the intended future use schedule, the settlement can be accelerated by implementing such means as wick drains. Wick drains provide orders of magnitude greater permeability than the surrounding sediments by creating a reduced drainage path for dissipating excess pore pressures induced the weight of overlying dredged material and capping material. The reduced drainage path length for the pore water reduces the consolidation time for the low permeability dredged material by providing a means to convey the pore water from the sediment relatively rapidly.

Facilities and Structures Adjacent to the CDF

Consolidation of the foundation soils and/or dredged fill may not only induce settlement within the footprints of the CDF, but may also induce settlement of the adjacent soils surrounding the CDF. In industrialized waterfront areas, structures often exist immediately adjacent to a planned CDF. Settlement induced by construction of the CDF may have an adverse impact on both pile-supported structures and facilities supported on shallow foundation. Therefore, consolidation settlement analyses must be extended to include potential impact to adjacent facilities. This was the case in the design of the St. Paul CDF, adjacent to which are several structures associated with the active saw and timber mill. These include two, 65-meter-diameter clarifier tanks. To avoid impacting these settlement-sensitive structures, settlement and finite element deformation analyses were conducted to determine a safe offset distance for CDF construction. An offset berm was design and constructed to further avoid impacting the clarifiers.

Habitat Considerations

Mitigation is often required to offset the loss of aquatic habitat from the filling of subaqueous areas to construct a CDF. Depending on site-specific considerations by regulatory agencies, the mitigation effort may be in the form of improved existing aquatic habitat or the creation of new aquatic habitat through the excavation of existing uplands. For the Thea Foss Project, a portion of the mitigation plan included an area of new habitat created by constructing a smaller "habitat" berm outside of the main containment berm and filling with fish-friendly substrates.

Conclusions

The design of a CDF is a complicated process, requiring geotechnical, chemical, and hydrogeological considerations to ensure effective containment of dredged sediments. Because each project has its own set of site-specific conditions and limitations, each design is unique, often requiring innovative solutions and specialized construction to achieve the project objectives. This paper described the general approach to a CDF design with two project examples illustrating the complexities of such a design.

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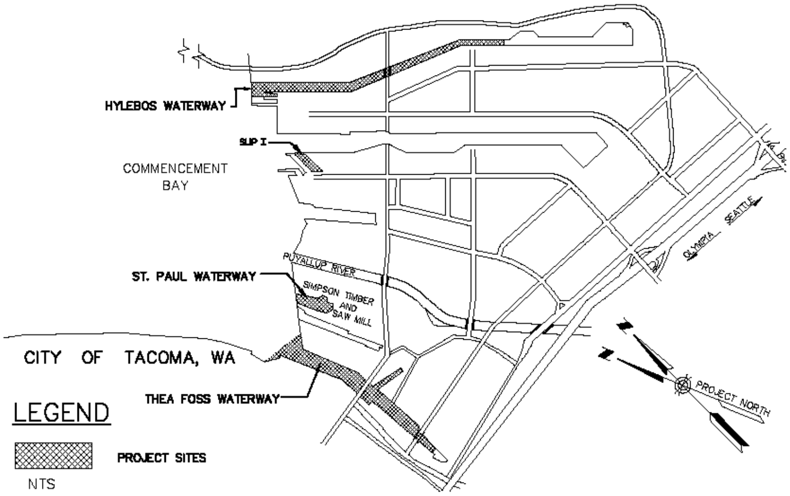

Figure 1. Site Map, Tacoma Washington.

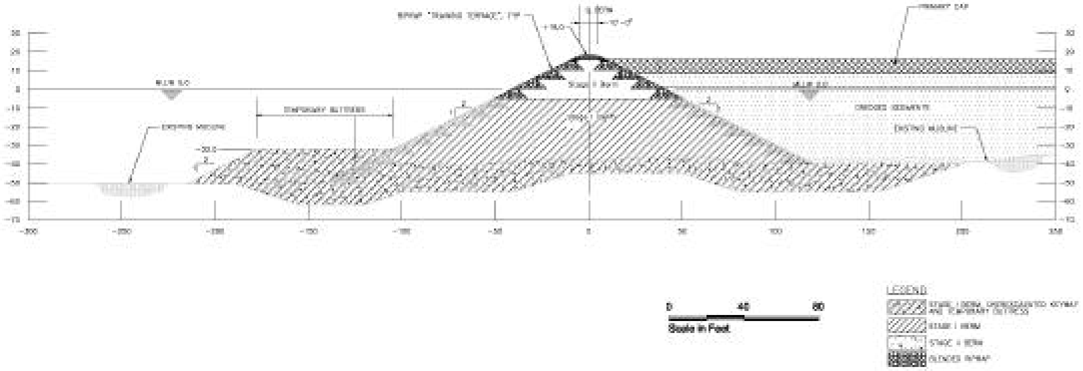

Figure 2. Cross-Section of the Slip 1 CDF Containment Berm.

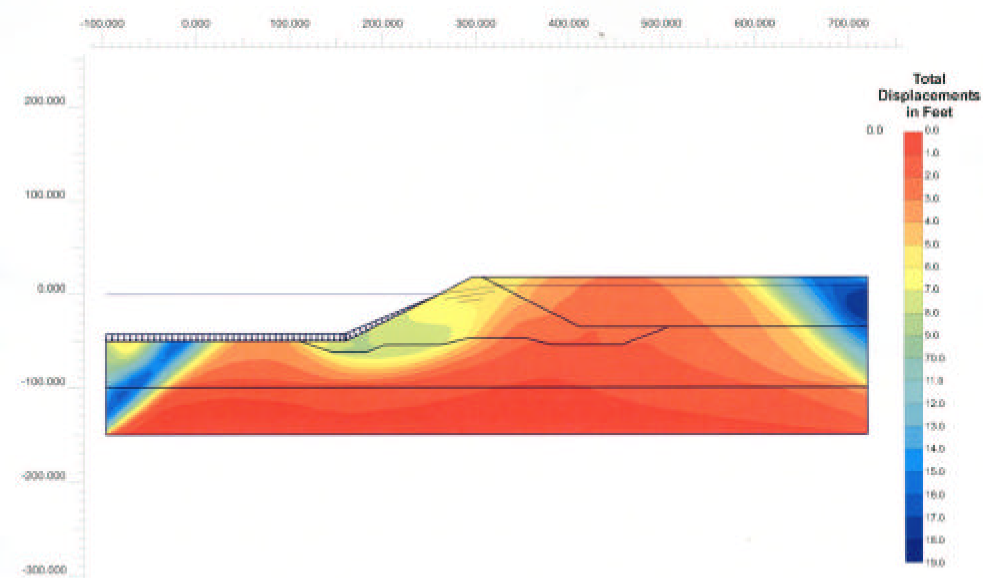

Figure 3. Seismic Deformation of the Slip 1 CDF Containment Berm.

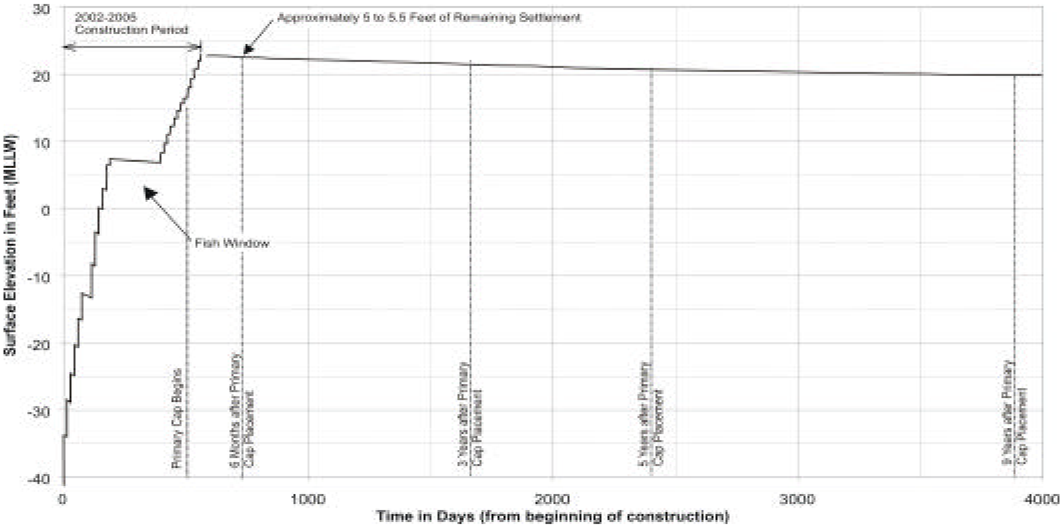

Figure 4. Predicted Dredged Fill Surface Elevation within CDF using PSDDF.