Dredged Material Management in Immersed Tube Tunnel Construction

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ABSTRACT: *Four case histories are described approximately 10 years apart, where unique solutions were implemented in the disposal of dredged materials for immersed tube tunnel construction. The earliest project in the 1970s used the dredged materials to construct a manmade island for the Second Hampton Roads Crossing in Virginia. The second project, the Fort McHenry Tunnel in Baltimore, built in the 1980s, separated clean and contaminated sediments and used the materials to reclaim the nearshore confined disposal facility (CDF) as a modern container terminal. The third, the Ted Williams Tunnel built in the 1990s in Boston Harbor, used large scale solidification/stabilization for contaminated sediments in an upland CDF. The most recent project, the Marmaray Rail Tunnel Crossing under the Bosphorus, will utilize a CDF for contaminated sediments—the first facility of its type in Turkey. The four projects illustrate a dramatic increase in dredging and disposal costs in the past three decades due primarily to continually tightening environmental restrictions. Furthermore, the escalating disposal costs threaten the economic feasibility of an otherwise attractive method of subaqueous tunnel construction.*

1 INTRODUCTION

Up until the 1970s dredged sediments were commonly disposed of in specially designated open water disposal sites. In immersed tube tunnel construction, the material dredged to form the tunnel trench would be temporarily stored underwater near the trench. Once the tubes were sunk, the material would be used as ordinary backfill to cover the immersed tubes. In 1980, during the planning and design of the Fort McHenry Tunnel in Baltimore that practice was deemed environmentally unacceptable. It has since become common practice to plan and engineer confined disposal facilities to mitigate negative environmental impacts.

2 SECOND HAMPTON ROADS CROSSING

In 1954, the Virginia Department of Highways and Transportation retained Parsons Brinckerhoff (PB) to design a crossing of the Hampton Roads ship channel. In 1957, the first Hampton Roads Bridge-Tunnel opened, connecting Hampton and Norfolk, Virginia across the James River, a major shipping channel. Twelve years later, in 1969, the firm was once again retained to provide design and construction inspection services for a parallel second crossing to meet increasing traffic demands. The Second Hampton Roads Crossing was opened to traffic in 1976.

The second crossing was composed of a 1,930-meter southern approach trestle; a 965-meter northern approach trestle; 600 meters of open approaches on the two enlarged portal islands; and a 1,920-meter immersed tube tunnel under the channel. During this project, dredged material was beneficially re-used to enlarge a man-made island used for the south tunnel portal (Figure 1), and the process was completed without polluting the water and with no damage to extensive clam and oyster beds and other nearby marine habitats. Although a federal environmental impact statement (EIS) was not required—as it would be today—all work was closely coordinated among various state and federal agencies and the construction industry to reduce the risk of disturbing or damaging the environment.

Figure 1. Enlarged man-made tunnel portal island.

3 FORT MCHENRY/SEAGIRT NEARSHORE CDF

As part of the design and construction work for the Fort McHenry Tunnel in Baltimore, PB was part of a joint venture that designed a nearshore CDF 3.2 kilometers from the tunnel site.

After a detailed study of alternative upland, nearshore and open water disposal site options, the 59-hectare Seagirt site in Baltimore Harbor was selected as the optimum location which provided sufficient capacity and met the design criteria and environmental requirements in regards to dredging, disposal, and construction. The $60 million disposal facility, which included a 1,700-meter cellular cofferdam offshore containment structure and 6-meter-high clay-lined upland perimeter dikes, was constructed so that it could be converted into a marine terminal by the Maryland Port Administration.

During the site search, PB evaluated various upland and harbor locations. Our findings were reported and reviewed in frequent meetings with the Interstate Division for Baltimore City (IDBC); the Federal Highway Administration (FHWA), which funded 90 percent of the cost of the tunnel, and an environmental task force composed of representatives of nine different federal, state, and local regulatory and permitting agencies. Because these agencies were regularly informed of our technical findings during the study of alternative sites, the required dredging and disposal permit for the selected site was obtained shortly after completion of the study. The proactive participation of the regulatory bodies in the site search was instrumental in streamlining and expediting the permitting process.

The principal environmental requirement governing the design of the CDF stated that any discharge from the disposal site could contain no more than 400 mg/L of suspended solids. Since the size of the site was too small for adequate settling basins, it was necessary to accelerate the settling of the solids from the dredge slurry by flocculation before the effluent could be discharged back into Baltimore Harbor.

The facility was designed to receive 2.7 million cubic meters of dredged material, including 460,000 cubic meters of highly contaminated sediments, excavated from the 55-meter trench for the construction of a twin-tube, eight-lane vehicular immersed tube tunnel. Subsurface profiles developed from borings drilled at the tunnel site indicated that the materials to be dredged would consist of very soft harbor bottom deposits (460,000 cubic meters), organic clayey and sandy silt deposits (500,000 cubic meters), gravelly sands (920,000 cubic meters), and stiff-to-hard clays and clayey silts (730,000 cubic meters).

The requirement to reclaim the CDF for the development of a marine terminal shortly after filling, was a major factor in the design of the Seagirt site. If all the dredged materials were placed in one area in an uncontrolled manner, the resulting non-homogenous fill would take many years to consolidate at great cost. To provide a design to accelerate site reclamation, the softest (and hardest to consolidate) materials which were also the contaminated shallow sediments were isolated and placed in a separate partitioned area. This area would require special ground improvement techniques and its development into usable land would take approximately 10 to 20 years. The better materials, e.g. sands and hard clays, were placed in the “spoil area” where a stabilization effort would commence soon after the completion of disposal operations.

The CDF capacity was engineered to accommodate the increased volume (bulking) of the materials after being dredged and redeposited. With allowance for bulking, which varies both with the type of material being dredged as well as the dredging method, the required disposal site design capacity was estimated at 3.8 million cubic meters.

The materials dredged by a cutter suction dredge were pumped the 3.2-kilometer distance from the tunnel trench by a 0.7-meter underwater pipeline to the disposal site where the contaminated materials were separated using shut-off valves on the pipeline (Figure 2). The effluent was diverted through shaft-type weirs into the treatment and the settling basins before discharge. Rapid mixers installed inside the weirs and slow mixers in the treatment basin accelerated the agglomeration of the flocculants.

Figure 2. Y-valves on the pipeline separated the clean and contaminated sediments during disposal operations.

The Seagirt nearshore CDF project (Figure 3) was the first major dredging project to be designed for effluent treatment by large-scale flocculation and sedimentation—a state-of-the-art system in dredged material disposal which has worked remarkably well in settling the finer solids in the effluent and containing them at the disposal site. During disposal operations, the solids that settled inside the settling basin were continuously removed by a small hydraulic dredge operating inside the basin to maintain the required ponding depth.

Figure 3. Seagirt nearshore CDF during construction.

To maximize capacity, the dredged material received in the disposal area was piled and compacted by bulldozers to build a 3.4-meter-high dike 30 meters behind the cells at the elevation of the land dikes at +6.4 meters. The land dikes were constructed of compacted granular fill and lined on the inside face with a clay blanket to prevent seepage. Dredging and disposal operations were completed on schedule (Figure 4). The site was later consolidated through ground improvement and converted into a container port by the Maryland Port Administration (Figure 5).

Figure 4. CDF at completion of disposal operations.

Figure 5. Seagirt CDF after conversion into marine terminal.

4 TED WILLIAMS TUNNEL/GOVERNORS ISLAND UPLAND CDF

In 1990, PB in joint venture, designed and managed the construction of a solidification/stabilization and upland CDF for the contaminated sediments dredged for the construction of the Ted Williams Tunnel in Boston. Earlier, in the late 1980s, the solidification/stabilization of contaminated marine sediments for reclamation projects was a state-of-the-art technology that had been tested in bench scale and applied in demonstration projects (mainly in Japan). The primary thrust of Japanese research was improving the handling and enhancement of bearing capacities for fill to improve or reclaim land, with minor emphasis on contaminant stabilization (Kita and Kubo 1983). In the U.S., such techniques had been used almost exclusively in oil and gas drilling operations and on wastes from power plants, sewage treatment, chemical manufacturing, and the nuclear industry. More than a decade later, the lime stabilization of dredged contaminated sediments in Boston represents the first known case history of a large-scale application of immobilization technology for contaminated harbor sediments in the U.S.

The construction of the tunnel required the excavation of a subaqueous trench to accommodate 11 immersed tubes to be sunk across the harbor. Approximately 840,000 cubic meters of material were dredged/excavated from the tunnel alignment that is across the main channel of Boston's Inner Harbor. Approximately 68,000 cubic meters of shallow marine sediments, from within 1.5 meters of the harbor bottom, were highly contaminated and did not meet Massachusetts requirements for open water disposal. It was therefore necessary to identify a suitable upland disposal site to meet Massachusetts Department of Environmental Protection (MDEP) regulations and permit requirements for disposal.

The contaminated fraction of the marine sediments were dredged by clamshell, chemically stabilized by adding quicklime, and contained in a lined and capped site on Governors Island adjacent to Logan International Airport. The site, owned by Massport, was made available on the condition that the materials be stabilized, solidified, and placed in a completely sealed environment. A design requirement called for the solidification of sediments in the shortest possible period after disposal, as additional land-excavated material from the East Boston portion of the tunnel construction would be filled over the stabilized sediments. To provide for adequate bearing capacity, the desired shear strength of the compacted solidified sediments was established as 207 kPa in order to accommodate a 4.6-meter-high embankment. Additionally, the convenient site adjacent to Logan Airport would later be reclaimed and developed into a parking area or used for storage facilities. To meet the environmental and engineering requirements, the dredged sediments were chemically stabilized and solidified by adding ten percent quicklime by volume.

The containment site was enclosed by a 4.6-meter-high dike and entirely lined with a double geomembrane sandwiching a geonet to intercept leachate in the event of a rupture in the primary geomembrane. A gravel and perforated pipe underdrain system was installed below the double liner to intercept high groundwater and drain it into a sump for long term monitoring. A leachate collection pump was also provided to collect any leachate intercepted by the geonet.

The lime admixture and mixing ratio were selected on the basis of a sampling and laboratory testing program on the marine sediments which included stabilization, solidification, and leaching tests with varying admixture proportions of lime, fly ash, kiln dust and cement. The primary goals were to design a method to stabilize the contaminants, as well as to rapidly solidify the soft sediments so that the CDF could be reclaimed for future use. Tests were conducted on raw samples and on mixed samples at various curing conditions to assess both the geotechnical properties and the leachability of contaminants. Test results indicated that the lime would react with the sediments to produce a pozzolanic reaction that would significantly improve the unconfined compressive strength of the sediments. Both Toxicity Characteristics Leaching Procedure (TCLP) tests and Sequential Batch Leach Tests (SBLT) indicated undetectable levels of contaminants in leachates from sediments mixed with powdered quicklime. Based on the test results, it was determined that the primary controlling parameters for a successful field mix would be uniform mixing, effective compaction, and a temperature greater than 4.4ºC during curing of the mix. Since the initial water content of raw dredged sediments is very high, it is necessary to either add sorbents or air-dry the amended sediments prior to compaction.

During construction, the sediments were dredged by clamshell, transported by scows to a silt curtain-enclosed unloading wharf, transferred into sealed trucks through a hopper, and hauled to the pre-constructed CDF. A fully satisfactory means for homogenous lime mixing was impossible to achieve in spite of the contractor's trials with several mixing locations and methods. Mixing in the open caused unacceptable lime dust propagation to the nearby airport. However, mixing in a pugmill was slow because of frequent mechanical breakdowns caused by debris in the dredged materials. Ultimately, the contractor was permitted to add and mix the lime within the CDF during periods of low air traffic—and when wind direction was away from the runways (Figure 6). As a result, most mixing work was performed at night, and airborne lime dust concentrations and winds were monitored to ensure compliance with the established criteria.

Figure 6. Governors Island CDF solidification/stabilization.

Massport and DEP also required odor control measures to prevent seagulls from being attracted to the sediments and straying into the path of aircraft. A special odor neutralizing foam was sprayed on the sediment stockpiles, forming a protective membrane after every hauling and mixing shift (Figure 7). During and after construction, a field sampling and laboratory testing program was carried out in the CDF to test the effectiveness of chemical stabilization and solidification. It was found that the amended sediments were completely stabilized as no detectable levels of contaminants were observed in periodic leachability testing on representative field samples. Required unconfined compressive strengths were also generally achieved. The stabilized sediments were leveled in the CDF, mechanically compacted in layers, and set aside for future land use. The total cost of the Governors Island CDF solidification and stabilization facility was approximately $5 million.

Figure 7. Odor neutralizing foam sprayed on sediment stockpiles.

5 MARMARAY RAIL TUNNEL CROSSING

This immersed tube tunnel crossing currently under construction beneath the Bosphorus involves a multiple of technical issues, both on land and beneath the waves. Excavation work is being undertaken in a historic district of Istanbul—a city designated as a World Heritage Site. As has been the case during past projects in this ancient city, encountering underground artifacts is a likely event during this major project.

Increasing the complexity of this construction are the challenges presented by the strait itself—one of the world's busiest international waterways. This narrow channel provides the only shipping access from the Mediterranean to Black Sea ports, in addition to handling a large volume of local marine traffic. The Bosphorus is also noteworthy for its two-layer water flow, consisting of an upper layer of freshwater runoff from the Black Sea as well as a salty lower layer of water migrating north from the Mediterranean to the Black Sea. It is within these swift currents that the immersed tube tunnel will be laid.

Although it is feasible to perform immersed tube placement operations in the Bosphorus using conventional methods, the heavy ship traffic and two-layer water flow will present significant construction challenges that will necessitate a great amount of care and careful planning. In part, this is because dredging, screeding and tube laying equipment and barges will not be permitted to block ship traffic and extensive safeguards will be necessary to guard against accidental collisions. Additionally, the two-layer water flow will become a factor as tube elements pass through the turbulent transition zone between the upper and lower water flows, setting up significant opposing hydrodynamic forces.

Subsurface investigations, including bathymetric and geophysical surveys, soil borings and laboratory tests performed in 1985 and 2003 identified and characterized the subaqueous soil and rock profile along the tunnel alignment. Soil characterization tests indicated that on the European side of the alignment, near the Golden Horn, the upper 1- to 3-meter layers of underwater sediments along a length of approximately 600 meters were contaminated, and therefore unsuitable for open water disposal. The limits of the contaminated sediments were delineated and the quantity of contaminated sediments to be dredged was established on the basis of dredged trench slopes of one vertical on three horizontal within those depths. The contaminated sediments will be dredged by closed environmental buckets and transported to a permitted CDF designed by the contractor. The CDF will be permanently capped upon the completion of disposal operations. The clean dredged material will be disposed of in open water at the designated historic disposal site at Cinarcik Basin in the Sea of Marmara (Figure 8).

Figure 8. Cinarcik Basin disposal site in the Marmara Sea.

Dredging and disposal operations will be sensitive to fish migrations, and curtailed during restrictive periods. Precautions will be taken to prevent any adverse impacts to the natural water flow, to keep the water clean, to minimize turbidity, and to meet the requirements of the Clean Water Act and related regulations. The Marmaray Project will be the first application of a CDF for contaminated dredged sediments in Turkey.

6 CONCLUSION

The four case histories presented in this paper illustrate the evolution of CDF design and permitting processes in the last 30 years: relatively simple handling of dredged materials in the 1970s during the construction of the Second Hampton Roads Crossing; to the $60 million CDF in Baltimore in the 1980s; to the $42 per cubic meter solidification/stabilization process in the 1990s in Boston; to the first CDF in Turkey today. All four projects have dealt with the dredging and disposal of contaminated sediments in a similar fashion in seeking a close review of the planning and design parameters and criteria by regulatory and permitting agencies, involving them very early in the planning stages. Environmental permitting rules require costly state of the art testing and analyses for sediment characterization and for containment mobility effects on the adjacent environment both during construction and in the long term.

Innovative engineering and construction techniques such as the temporary wastewater treatment facilities at the Seagirt CDF and the solidification/stabilization process application at the Governors Island CDF are no longer isolated exceptional case histories. On the contrary, such progressive practices are becoming commonplace to meet more and more severe environmental and regulatory criteria. All these projects demonstrate that the scarcity and high real estate value of nearshore and upland sites in proximity to dredging projects make it necessary to design confined disposal facilities that can be converted into usable land at the completion of disposal operations. Finally, the beneficial use of dredged materials, whether amended or naturally pristine clean, is mandatory as the only alternative to costly CDFs, as open water disposal is no longer an option. Experience shows that we must be prepared to stand up to ever-growing engineering challenges to deal with contaminated dredged sediments lest the dramatic increase in disposal costs threaten the economic feasibility of immersed tube tunnel construction.

7 REFERENCES

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