U.S. Army Corps of Engineers

Baltimore District

Baltimore Metropolitan
Coastal Storm Risk Management Feasibility Study

APPENDIX D

Geotechnical Analysis

FINAL REPORT

February 2024

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1 INTRODUCTION

This report presents the results of the geotechnical engineering evaluation of the area covered by the Baltimore Coastal Storm Risk Management (CSRM) study. The purpose of this report is to document the existing geotechnical conditions of the study area and to provide geotechnical information in support of the final array of alternatives in the Feasibility Study. In accordance with the Corps Smart Planning Process, the design level in this study is considered to be 10 percent.

The Baltimore District Corps of Engineers (NAB) is conducting a coastal storm risk management (CSRM) study for the Baltimore coastline from Coffin Point, the site of Maryland Transportation Authority offices at the Francis Scott Key Bridge (I-695) to the Cox Creek Dredged Material Containment Facility, immediately south of the Francis Scott Key Bridge (See Figure 1 below). Because it is a critical transportation asset, the Martin State Airport was included in the study at the request of project's non-federal sponsor, the Maryland Department of Transportation (MDOT).

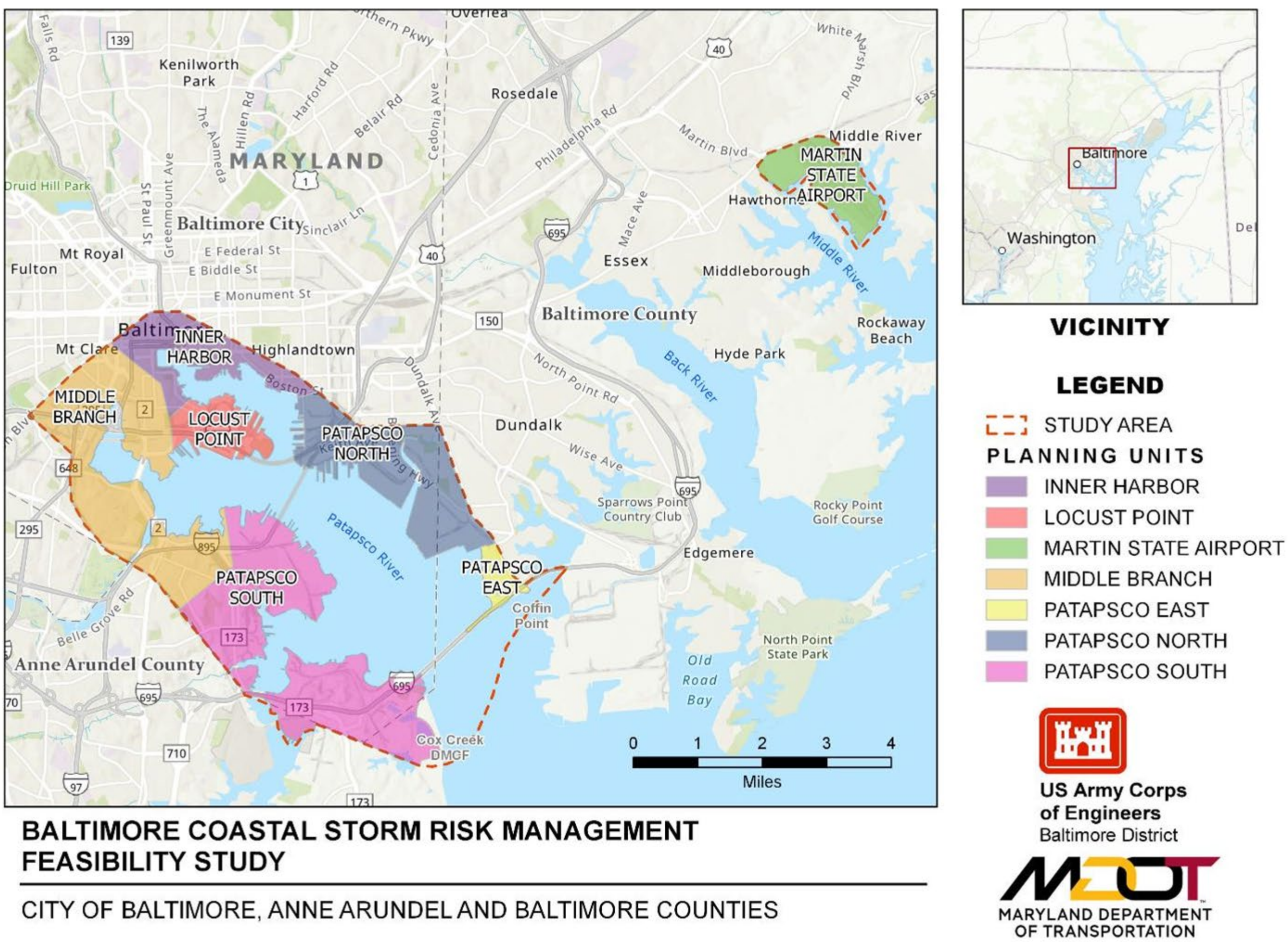

Figure 1 Study Area and Planning Units

2 STUDY ALTERNATIVES

Ten alternatives, plus "the no action plan" were considered as part of this study. Alternatives 4 to 7 were selected to move forward for this feasibility study and are briefly summarized as follows:

Alternative 4 – Critical Infrastructure Only: This alternative consists of very limited structural measures designed to protect those most vulnerable critical facility – namely the interstate tunnels under the harbor. These would consist of floodwalls, with closure structures as needed, immediately surrounding the vulnerable assets.

Alternative 5 – Critical Infrastructure and Nonstructural: This alternative provides full protection for critical transportation assets, and implements selective nonstructural solutions (floodproofing, relocation) for other at-risk structures not provided by a more robust line of defense.

Alternative 6 – Critical Balanced: This alternative expands Alternative 5 to include the addition of a structural line-of-defense, in the form of an elevated bulkhead/seawall (or "sea curb") along the shoreline of the Port of Baltimore's Seagirt and Dundalk terminals. This line of defense would extend upstream along the right bank of Colgate Creek, to prevent flanking flooding of Broening Highway and the entrance for trucks into Seagirt.

Alternative 7 – Mid-Tier Balanced: This alternative builds upon Alternative 6 by adding structural lines of defense along vulnerable portions of the Inner Harbor, Locust Point, Middle Branch and Martin State Airport. Specifically, this alternative would incorporate floodwalls (fixed and deployable) along vulnerable portions of Canton, Fells Point, Locust Point and Middle Branch, and generally be located along the shoreline. It would also include the creation of a levee via the elevation of Wilson Point Road at Martin State Airport.

Alternative 5A: Critical Infrastructure with Select Nonstructural Plan is proposed as the Recommended Plan. This plan includes constructing a concrete floodwall around the interstate I-95 and I-895 tunnel entrances and associated critical infrastructure (ventilation buildings) as shown in Figure 2.

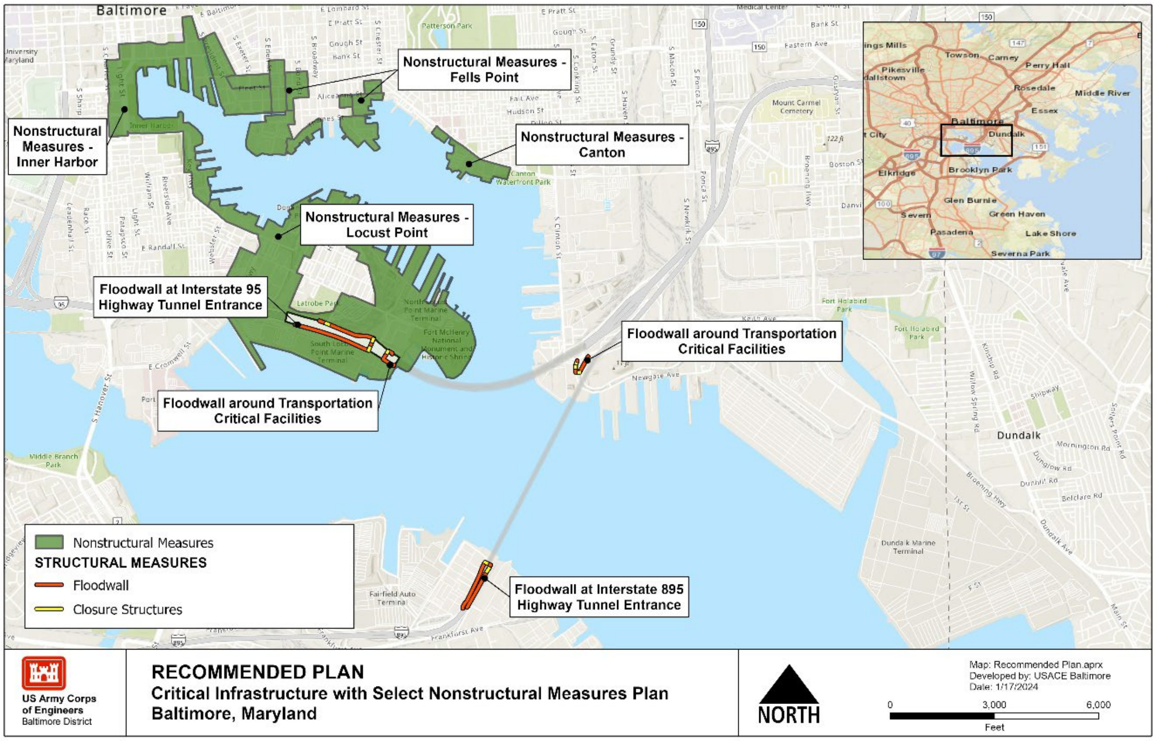

Figure 2 Proposed Recommended Plan

3 Regional Geology

Maryland is part of six distinct physiographic provinces: (1) the Atlantic Continental Shelf Province, (2) the Coastal Plain Province, (3) the Piedmont Plateau Province, (4) the Blue Ridge Province, (5) the Ridge and Valley Province, and (6) the Appalachian Plateaus Provinces. These extend in belts of varying width along the eastern edge of the North American continent from Newfoundland to the Gulf of Mexico.

The study area is in the Aberdeen Estuaries and Lowlands District of the Coastal Plain physiographic province (Figure 3). This geologic district has essentially flat-lying sedimentary beds and a relatively featureless lowland. The Coastal Plain consists of layers of sediment laid down in ancient marine, estuarine, and riverine environments tens of millions of years ago. These sedimentary deposits originated from changes in sea level over geologic time that allowed deposition of sediment when the area was flooded by ancient seas. Coastal Plain sediments form wedge-shaped layers which thicken in depth toward the east but form only in a relatively thin veneer over the crystalline basement rock in the study area. Coastal Plain deposits are about 20 feet thick at the mouth of the Gwynns Falls in the Middle Branch. Piedmont rocks underlie these sedimentary deposits of the Coastal Plain. Iron deposits within the Coastal Plain portion of the watershed provided ore for an iron-producing industry beginning in the late 1700s and continuing through the early 1800s. The sedimentary deposits consist of fine to medium sand, often micaceous, and gravel; lesser amounts of silt and clay; gabbro and granite boulders (to 8 ft.) occur near Stump Point and Mill Creek south and east of Perryville.

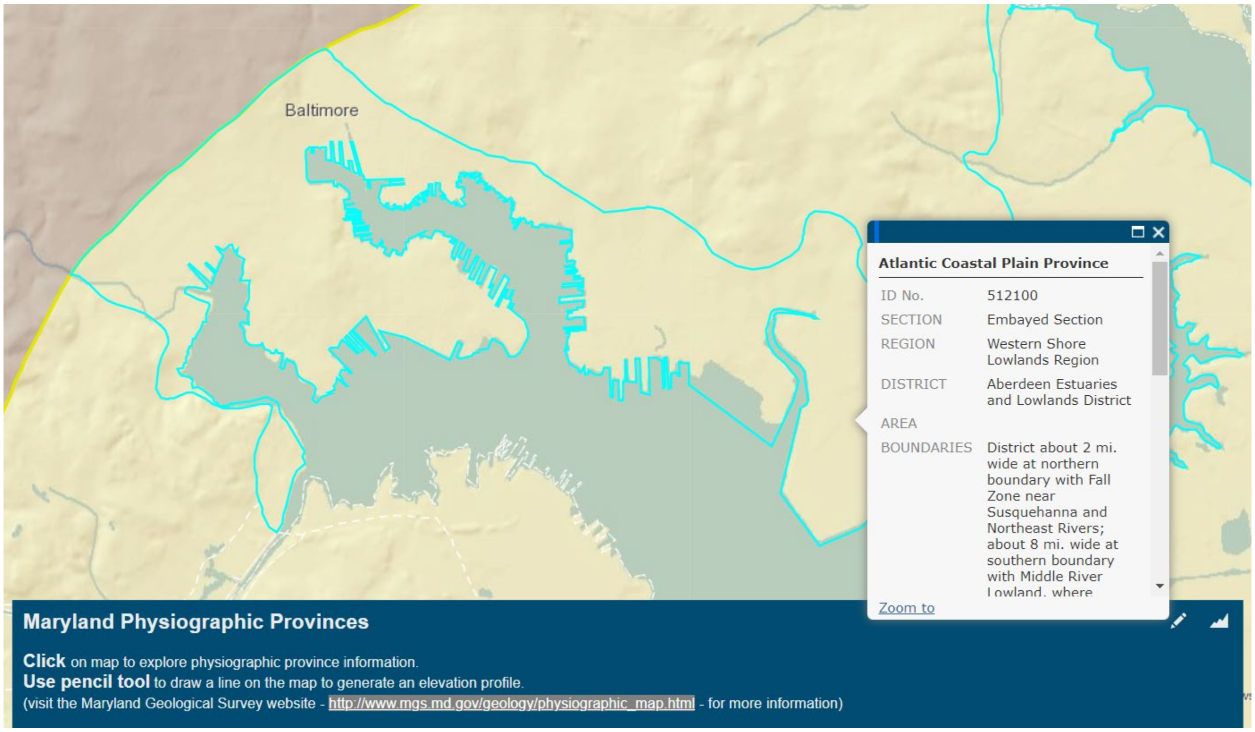

Figure 3 Regional Geology of the Project Site

4 EXISTING GEOTECHNICAL INFORMATION

4.1 MARTIN STATE AIRPORT PLANNING UNIT

T.L. B. Associates conducted a geotechnical study for the Black and Decker Hanger Apron, Taxilane and Parking lot project at the Martine State Airport in 2005. The geotechnical investigation consisted of drilling 19 pavement borings and 5 structural borings. All pavement borings were advanced to a depth of 10-feet while the structural borings were between 48.8 and 50 feet deep. The subsurface conditions encountered at the Martin State Airport are summarized as follows:

Topsoil measuring between 1.0 feet and 5 inches thick was encountered.

Fills comprised of fine to coarse sand with little silt and clay, trace gravel or sandy clay with silt and gravel measuring 2 to 10 feet were encountered. The Standard Penetration Test (SPT) N-values in this layer were typically 11-25 blows per foot (blows/ft).

Silty/sandy clay with fine to coarse sand was encountered under the fill layer in a third of the borings drilled in this project. At a few locations, this layer was encountered beneath a layer of sand under the fill. The SPT N -values in this layer varied from 5 blows/ft to 33 blows/ft, suggesting soft to stiff consistency.

Sand, clayey fine to coarse sand with silt and gravel was encountered in more than two-thirds of the borings drilled in this project. The SPT N-values varied between 5 and 48 blows per foot, suggesting very loose to dense in-situ conditions. At depths greater than 25 feet below the existing ground level, the SPT N-values are consistently greater than 50 blows/ft, suggesting very dense in-situ conditions.

4.2 Patapsco North Planning Unit

A geotechnical investigation of the construction of the Seagirt Terminal Berth-IV was conducted in 2010 by D. W. Kozera, Inc. This investigation was comprised of six borings on the land side, six borings within the existing cells, and six borings in the water outboard of the existing cells. All borings were advanced to depths of 100 to 140 feet below the ground or water surface. The depth to harbor bottom varied from 12 to 40 feet at the water boring locations. The test borings indicate the following generalized subsurface stratigraphy.

Miscellaneous fill consists of granular dredge material placed on the western portion of the site. The depth of miscellaneous fill extends to a depth of 35 feet below ground surface and consists of clayey sand, silty sand, poorly graded sand and sandy silt. The SPT blow count within the fill layer varies from weight of hammer (WHO) to 10 blows/ft.

Muck slurry consists of fine-grained dredge material placed on the eastern portion of the site. The depth of muck slurry encountered on the east side is below the miscellaneous fill to approximate depths of 25 to 30 feet below the ground surface. The SPT blow count varies from 2 to 3 blows/ft within the muck slurry layer.

Recent alluvial soils were encountered below the miscellaneous fill and the muck slurry and consist of soft elastic silt and organic clay soil. In this stratum, the recent alluvial soils on the land side and within the cells appear to be stiffer than those outboard of the cell due to the consolidation under surcharge loading of the sand fill placed within the cell. The recent alluvial soils extend to an elevation of EL-38 to EL-43. The SPT blow count within the layer varies from WOH to 4 blows/ft.

Basal alluvial soils are younger sediments as compared to the Cretaceous Age Potomac Group Soils. Basal alluvial soils consisting of medium dense sand and gravel. Medium stiff clay layers were also encountered in some borings. The basal alluvial soils extend to an elevation of EL-50 to EL-70 and the SPT values within this layer varies from 2 to 34 blows/ft.

Cretaceous Age Potomac Group Soils were encountered at EL-50 to EL-70 and extend to the maximum depth of borings at EL-100 to EL-130. This stratum consists of very stiff Arundel Clays underlain by dense sand and silts. The SPT values within this stratum vary from 20 blows/ft to 50 blows/2 inches.

Groundwater was encountered from all landside borings and varies from depths of approximately 3 to 10 feet below ground surface. This groundwater level is expected to vary with the adjacent harbor tide levels.

In 2019, a geotechnical investigation was conducted in support of the Seagirt Loop Channel Deepening project in Baltimore, Maryland, for which 56 borings (PR-1 to PR-56) were drilled. Silt and clay were encountered full depth in all borings except in PR-16, PR-36, PR-39, PR-46, and PR-51 through PR-56. The SPT N values for clay and silt ranged from weight of rod (WOR) over 18-inches to 15 blows/ft, indicating very soft to stiff relative consistencies. Interbedded sand layers were encountered within this clay and silt in borings PR-23, PR-35, PR-47, and PR-53 with SPT N values ranging from 1 to 7 blows/ft, indicating very loose to lose relative consistencies. Sand was encountered in borings PR-16, PR-36, PR-39, PR-46, and PR-51 to PR-56 about EL. 29.7 to EL.54.3 and continued through boring termination depth. The SPT N values for this sand ranged from 2 to 27 blows/ft, indicating very loose to medium dense relative consistencies. Very loose clay and silt layers were encountered within this sand strata at Boring B-39 below elevation EL.-29.7 feet.

4.3 LOCUST POINT PLANNING UNIT

Soil boring information is available from the South Locust Point Marine Terminal Project, Marginal Wharf and Related Work (MDOT Contract No. M.P.A. -E71-1SL) dated 1973.

Typically, the land borings consist of granular dredged fill material. The fill extends to a depth of between 10 to 40 feet below ground surface and consist of sand, silty sand, gravel and sandy clay. The SPT blow count within the fill layer varies from WOH to 25 blows/ft.

Loose and soft recent alluvial soil typically exhibiting WOH to 2 blows/ft, was encountered below the miscellaneous fill layer for the land borings and at mudline for the harbor borings. This layer consists of silt w/mica, sandy silt and had thickness extended to 25 feet. It should be noted that some borings did not encounter the loose and soft recent alluvial soil.

A competent silt, sand and gravel layer, with a SPT blow count above 10 blows/ft was encountered below the recent alluvial soil.

5 GENERALIZED SUBSURFACE PROFILE

No site-specific geotechnical investigation and laboratory testing program was performed in the vicinity of the Interstate I-95 and I-895 tunnel entrances and associated critical infrastructure, as a part of this study. Limited information for the adjacent planning unit is available and is briefly summarized in Section 4. Existing nearby subsurface investigations were reviewed to produce a generalized subsurface profile. For the purpose of the TSP phase, the PDT assumes that the geotechnical conditions at the I-95 and I-895 tunnel entrances and associated critical infrastructure are similar to those encountered for the construction of the Seagirt Terminal Berth-IV (Patapsco North Planning Unit). A conceptual local geology setting was assumed to consist of recent geologic deposits of alluvial soils overlain by artificial fill soils, and dredge material fill. Underlying the recent alluvial soils are the basal alluvial deposits of granular soils underlain by Cretaceous aged Potomac Group soils. The Potomac group soils consist of very stiff clay of the Arundel Formation underlain by dense sands. The generalized subsurface profile consists of Miscellaneous Fill extending to approximately 15 feet below ground surface, underlain with 10 feet of Recent Alluvial material and then underlain with Potomac Sand. The Miscellaneous Fill consists of granular dredged material such as clayey sand, silty sand, and silt. The Recent Alluvial layer is assumed to consist of soft elastic silt. The Potomac Sand is assumed to be dense sand. Figure 4 below shows the proposed generalized subsurface profile with the estimated soil design parameters. Soil design parameters such as bulk density, effective strength parameters (c' & ϕ') and earth pressure coefficients (K_0, K_A, K_p) are also listed in Table 1. The estimated design values: Bulk Density Effective strength parameters in Figure 4 and Table 1 are based on the values from Seagirt Terminal, Berth IV-Geotechnical report by D. W. Kozera, Inc. They developed these soil parameters for Sheet pile Cut-off wall based on the soil borings performed and the soil laboratory tests (soil classification tests, two CU triaxial tests, & two unconfined compression tests) and the available empirical relations of soil parameters to the SPT values. It should no noted that the generalized subsurface profile and these design values are only rough estimates for this feasibility study and a very rough design for cost purpose and not for detail and final flood walls design. Further data collection and analyses will be necessary during the Planning, Engineering, and Design (PED) phase of this study.

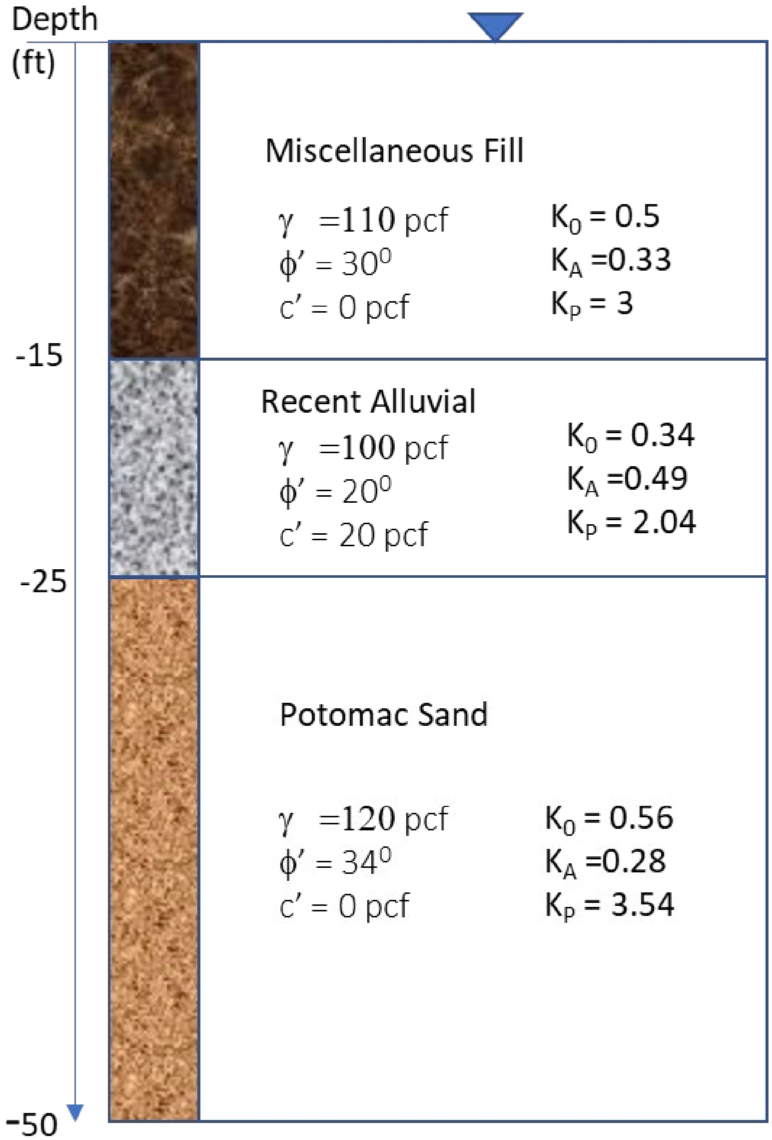

Figure 4 Proposed Generalized Subsurface Profile and Design Soil Parameter

Table 1 Estimated Design Parameters of On-Site Soils for Floodwall Analysis

Soil Type	Bulk Density	Effective	Effective	Lateral Earth Pressure Coefficient		

	(pcf)	Cohesion (c’)	Friction Angle (ϕ’)	At Rest (K_0)	Active (K_A)	Passive (K_P)
Miscellaneous Fill	110	0	30	0.50	0.33	3.00
Recent Alluvial	100	20	20	0.34	0.49	2.04
Potomac Sand	120	0	34	0.56	0.28	3.54

6 GEOTECHNICAL ASPECTS OF FEASIBILITY STUDY MEASURES (10% DESIGN)

6.1 FLOODWALL DESIGN

The most common types of flood walls are Cantilever T-type and cantilever I-type walls, as shown in Figure 5. Most flood walls are of the inverted T-type wall. The cross bar of the T serves as a base and the stem serves as the water barrier. When founded on earth, a vertical base key is sometimes used to increase resistance to horizontal movement. Due to the closeness of the walls to the existing structures and the risk of disturbance or damage to adjacent foundations, I-type flood walls consisting of driven sheet piles capped by a concrete wall are not recommended at this 10 percent design stage, and T-type flood walls are recommended for a conservative initial cost estimate. At this stage of feasibility study measures (10% design), no site-specific geotechnical investigation and testing program were conducted. Based on the provided rough geotechnical profile, it is assumed at this stage that the walls can be supported by a shallow foundation with an allowable bearing pressure of 2,000 psf. It is further assumed that no special foundation treatment or seepage control is needed at this stage. Foundation treatment and seepage control for the flood walls should be addressed in later design stages after site-specific core boring logs are available. A sheet pile cutoff was not included in this stage of preliminary T wall design for controlling seepage but shall be considered in the final design if deemed necessary. However, as the project proceeds, the design team shall consider sheet pile I-wall as a potential cost-saving measure. I-wall sheet pile should be installed with press-in method to eliminate vibration and damage to adjacent features.

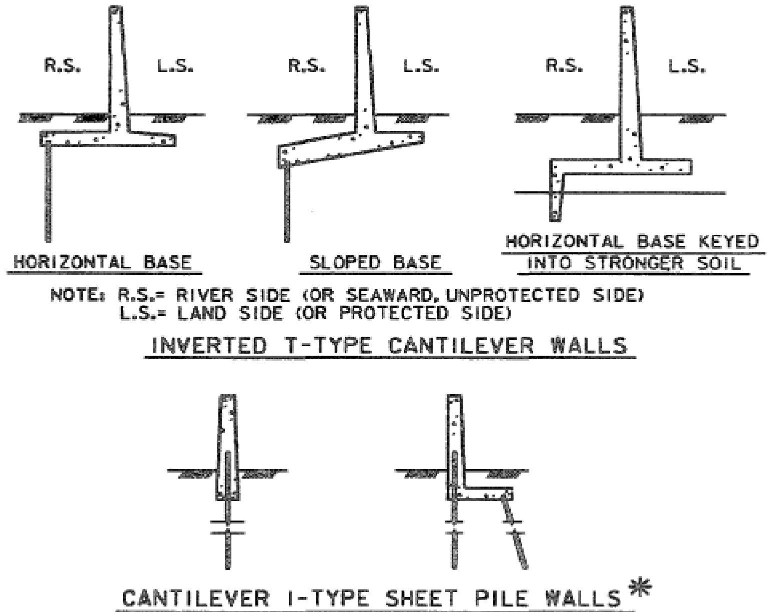

Figure 5 Most Common Types of Flood Walls

Generally, it is more difficult to design stable flood walls than retaining walls. Flood walls are often constructed in a flood plain which may have poor foundation conditions. Uplift is a critical design consideration with flood walls. The water load on a flood wall can be more severe, especially when wave loading is applicable. When the groundwater surface is near or above the wall footing, a common occurrence with flood walls, the allowable bearing capacity of the soil is reduced. The reduction of stability, due to the erosion of the earth cover over and beyond the base, must also be considered.

Further data collection and analyses will be necessary during the Planning, Engineering, and Design (PED) phase of this study. At this 10% design, the assumed preliminary geotechnical profile appears suitable to provide shallow foundation support for the floodwalls. However, the additional site-specific geotechnical investigation in the vicinity of the Interstate I-95 and I-895 tunnel entrances may encounter deep, soft uncontrolled fill thus pointing to deep foundation options (e.g., pile foundations or drilled shafts) as the only viable foundation support alternative. If undesirable foundation conditions are encountered, there are some ground improvement options such as undercut and replacement, pre-loading, compaction grouting, and soil densification that could permit the use of shallow foundations at a lower total cost than other comparable deep foundation alternatives. These ground improvement options shall be evaluated before making the final foundation recommendation and design.

6.2 CONSTRUCTABILITY

Earth foundation should be properly compacted and should be clean and damp before concrete is placed. A concrete mix design should be engineered to satisfy strength and durability requirements. The dimensions of the wall should be such that reinforcement and concrete can be properly placed. The top thickness of the stem for cantilever concrete walls over 8 feet high and for base slabs should be a minimum of 12 inches to facilitate concrete placement. Stems less than 8 feet high with one layer of vertical reinforcement may be 8 inches thick. The design should address construction constrains due to the location of the wall. The wall design should include joints to allow expansion, contraction, and/or to divide the structure into the convenient working units. Water stops are required across joints where watertightness is required.

Backfill material should be carefully selected and properly compacted in accordance with design specifications. Clean sands and gravels are the most suitable materials because they drain rapidly, are not susceptible to frost action, and provide both strength and stability. It is advisable to use locally available material as much as practical, but importation of material may also be necessary to mitigate poor foundation material or seepage. All walls must have mechanisms to prevent or reduce infiltration of rainwater and adequate surface drainage to dispose of surface water. Backfill should be brought up equally on both sides until the lower side finished grade is reached.

7 REFERENCES

USACE EM 1110-2-2502, Design of Retaining and Flood Walls, 29 September 1989

USACE EM 1110-2-1614, Design of Coastal Revetments, Seawalls, and Buckheads, 30 June 1995

Geotechnical Report, Black and Decker Hangar Apron, Taxilane, and Parking Lot, Glenn L. Martin State Airport, February 8, 2005

Geotechnical Report, DMT Berths 1, 2, and 3 Borings for Dredge Material Sampling, October 1, 2019

Geotechnical Investigation Report, Seagirt Berth 3 Dredging and Masonville Unloading Basin Dredging, May 2019

Geotechnical Engineering Study, Seagirt Terminal Berth-IV, March 25, 2010

South Locust Point Terminal Pages from E71-1SL_2 Binder_Pier 9.pdf, Maryland Port Administration.

Maryland Geologic Survey Website: http//www.mgs.gov/geology/physiographic_map.html
Physiographic Map of Maryland (md.gov)