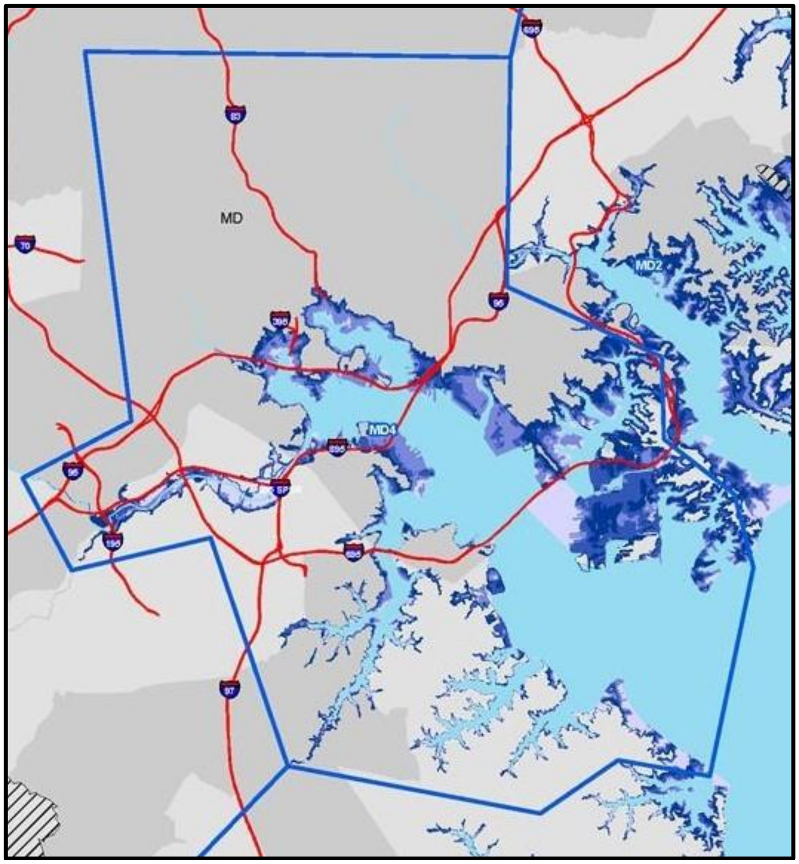
Baltimore Coastal Storm Risk Management Feasibility Study

Appendix A: Civil Engineering



City of Baltimore, Anne Arundel and Baltimore Counties
July 2022

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MARYLAND DEPARTMENT OF TRANSPORTATION

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Engineering Appendix- Civil Engineering

Baltimore Coastal Storm Risk Management

Feasibility Study

April 2022

1. Introduction

1.1. Purpose and Scope of the Appendix

The purpose of this appendix is to present the Civil Engineering investigations/studies conducted for the Feasibility Study, Baltimore Coastal Storm Risk Management. This Appendix investigated and evaluated a holistic way of reducing risk to the study area from inundations associated with storm frequencies ranging from the 25-year to the 100-year. Many flood risk management structures were assessed, evaluated, and ranked as partially and marginally feasible through the project matrix elimination process. The two flood risk management structures selected were floodwall, and road elevation.

This civil engineering design investigation resulted in the preliminary design of these two structures at strategic locations as a product of Hydrologic and Hydraulic (H&H) studies given water surface elevations at multiple control areas critical to the flood risk reduction of the study area. The designs were sufficient to generate baseline quantities and cost estimates to determine the cost of all the structural alternatives within the project for the feasibility study.

2. Existing Conditions

2.1. Study Area

The study area covered by this Appendix includes Locust Point, Inner Harbor, North Patapsco, South Patapsco, Middle Branch and Martin State Airport.

2.2. Site Description

The site area consists of a mix of residential, commercial and transportation infrastructure.

- The Inner Harbor alignment consists of the waterfront of Baltimore Museum of Industry to Canton Waterfront Park. This alignment is approximately 6.3 miles of floodwall. See **Figure 1**, Study Area.

- Locust Point alignment consists of Fort McHenry I-95 tunnel and the tunnel ventilation building, US Naval Reserve Building and Domino Sugar Waterfront to the Baltimore Museum of Industry. This alignment is approximately 2.3 miles of floodwall. See **Figure 2**, Study Area.
- North Patapsco alignment consists of the Seagirt Marine Terminal Port of Baltimore. This alignment is approximately 2.7 miles of floodwall. See **Figure 3**, Study Area.
- South Patapsco alignment consists of the 895 Tunnel and West Ventilation Building. This alignment is approximately 0.6 miles of floodwall. See **Figure 4**, Study Area.
- Middle Branch alignment consists in of the Wheelabrator Baltimore Building and is approximately 0.5 miles of floodwall. See **Figure 5**, Study Area.
- Martin State Airport consists of the Wilson Point Road and Lynbrook Road. This alignment is approximately 0.75 miles of road elevation. See **Figure 6**, Study Area.

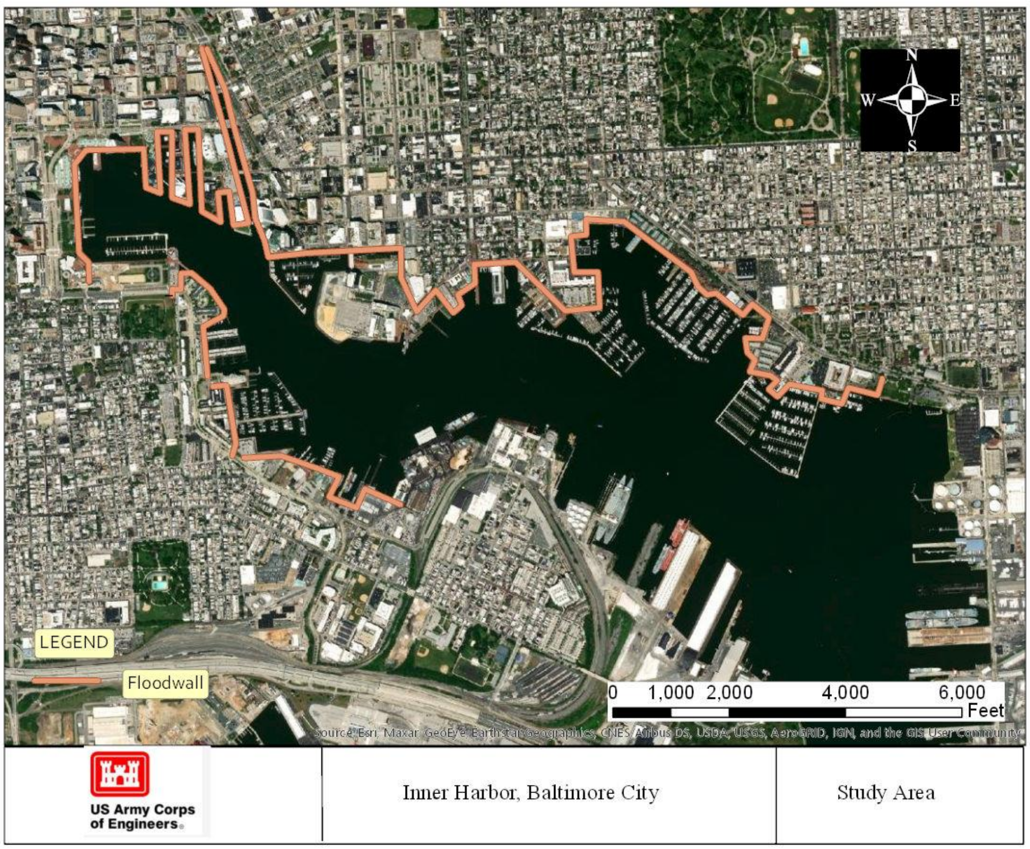

Figure 1, Study Area -Inner Harbor

US Army Corps of Engineers	Locust Point, Baltimore City	Study Area

Figure 2, Study Area- Locust Point (Fort McHenry, 95 tunnel, West Ventilation Building and Tide Point)

Figure 3, Study Area – Port of Baltimore-Seagirt

Figure 4, Study Area- 895 Tunnel and Ventilation Building

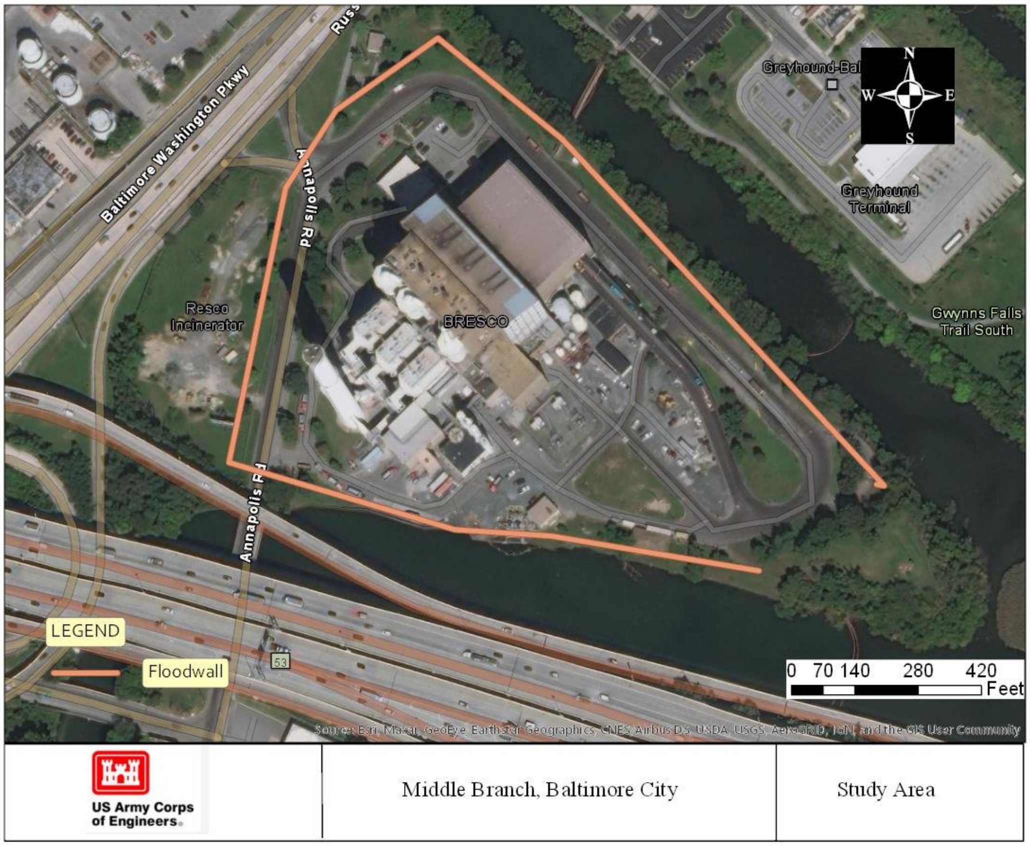

Figure 5, Study Area- Middle Branch

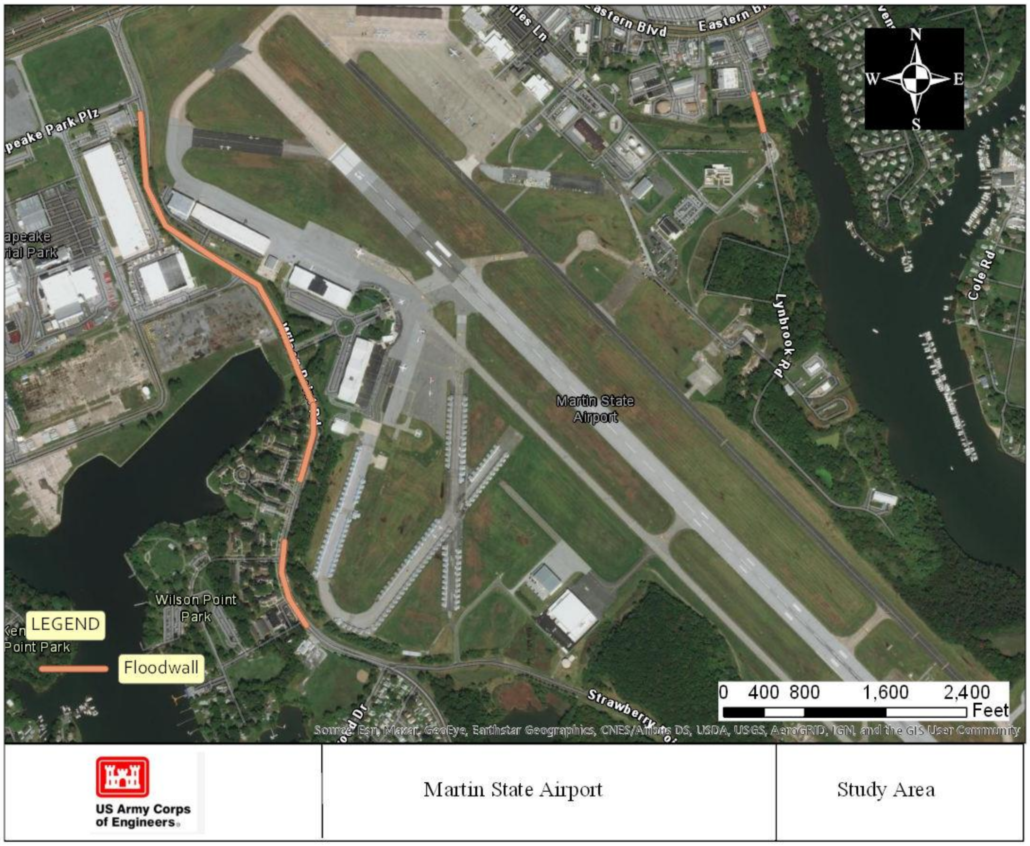

Figure 6, Study Area- Martin State Airport

3. Applicable Design Standards and Criteria

3.1. General

Improvements to site protection form floodwaters are required to follow federal, state, and local standards. Emphasis is on the use of USACE engineering circulars and manuals. For road works standard and specifications from municipal and county should be followed.

3.2. Design Criteria

The floodwalls for all the alternatives were designed to an intermediate sea level rise of a 100-year storm. The value was provided by H&H following the Annual Exceedance Probability and it was 9.2 feet plus 3 feet of freeboard. The length of the alignment was estimated utilizing data from the LIDAR survey provided by Planning Division. The floodwall limits were based on tying into high ground at elevation 12.2 feet and

NAVD88 datum. The limit of disturbance used for the construction of the floodwall was 15 feet to each side. Martin State Airport proposes to elevate existing roads to serve as flood protection and as an emergency exit for the people living around the area and personnel working on the airport. With the airport being a critical infrastructure, a level of performance of a 1000-year level was evaluated but due to project site constraints it was decided it was not feasible.

3.3. Civil

AutoCAD Civil 3D and ArcPro GIS were used to create the alignments, cross sections and layouts for the floodwalls and road elevations. Typical cross sections of floodwalls were developed utilizing design guidance from EM 1110-2-2502, Retaining and Floodwalls, Chapter 5- Design of Floodwalls and Levees, FEMA (44 CFR60.3(c)(2)). See **Figure 1,** Typical Cross Sections**.**

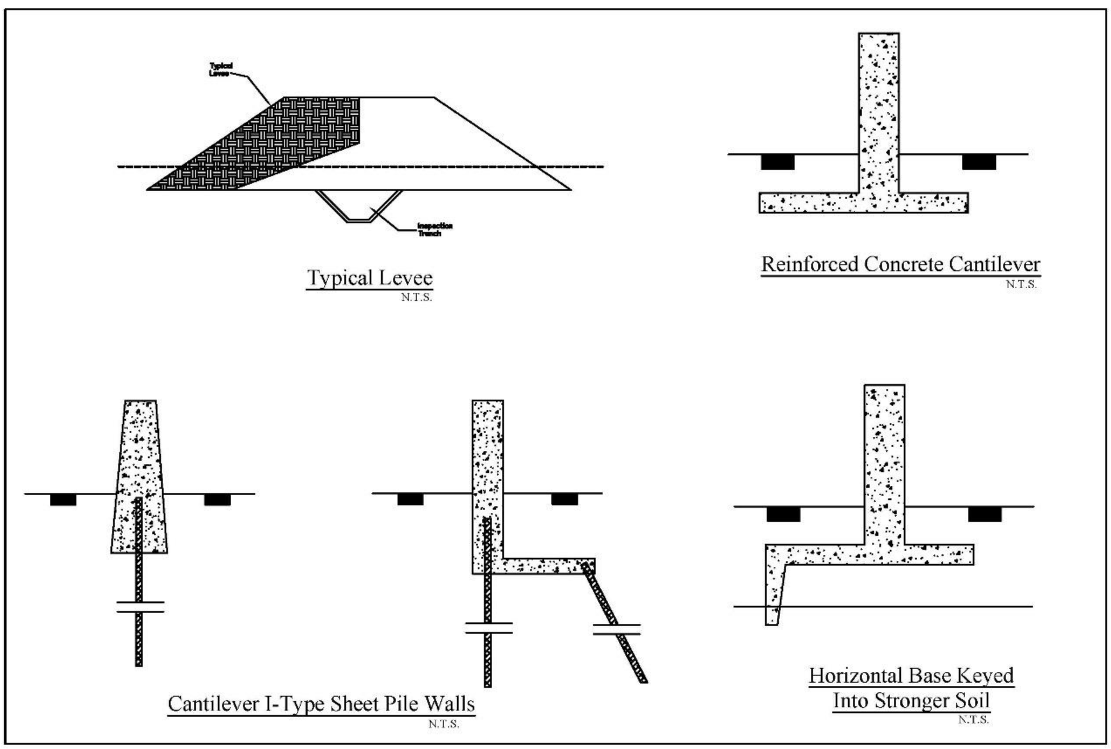

Figure 7, Typical Cross Sections

4. Structural Analysis

4.1. Floodwalls

The floodwalls considered for the protection of the I-95 and I-895 tunnels are cast-in-place concrete T-walls. Two different types of floodwalls were selected and referenced as Type 1 and Type 2. Floodwall Type 1 will be constructed around tunnel entrances while Type 2 will be constructed to protect the tunnel ventilation buildings.

Analysis and Design of Floodwalls

The concrete T-walls were analyzed for global stability and structural strength based on the requirements established on EM 1110-2-2100 “Stability Analysis of Concrete Structures”, EM 1110-2-2502 “Retaining and Floodwalls”, Engineering and Construction Bulletin (ECB) No. 2017-2 “Revision and Clarification of EM 2100 and EM 2502”, and EM 1110-2-2104 “Strength Design for Reinforced Concrete Hydraulic Structures”.

Five different loading conditions were used during the analysis in accordance with Table B-5 of EM 1110-2-2100, see Table 1. An additional loading condition, Design Resiliency Check (DRC), was also used and includes water at the top of the wall. This case was adapted from the USACE New Orleans District Design Guidelines and applies to structures whose primary function is hurricane flood protection. The case was developed to verify the survivability of a structure during major storm events. As shown on Figure 1 and considering the floodwalls as critical structures, Table 1 of ECB No. 2017-2 classifies these loading conditions into three (3) different categories: usual (<10 year recurrence interval), unusual (10-750 year recurrence interval), and extreme (>750 year recurrence interval).

The controlling case for the design of the floodwalls was the Design Resiliency Check (DRC) case, water at top of wall.

Load Case	Loading Description	Classification
C1	Surge Stillwater + Coincident Wave	UN/E[1]
C2a	Coincident Pool + OBE	UN
C2b	Coincident Pool + MDE	E
C3	Construction	UN
C4	Normal Operating	UN
Additional Case (DRC)[2]	Water at Top of Wall + Coincident Wave	UN/E

[1] UN = Unusual, E = Extreme; [2] DRC = Design Resiliency Check

Table 1 - Coastal Floodwall Loading Condition Classification

Table 1 (EM 1110-2-2100, Table 3-1) Load Condition Probabilities

Load Condition Categories	Annual Probability (p)	Return Period (t_r)
Usual	Greater than or equal to 0.10	Less than or equal to 10 years
Unusual (normal structures)	Less than 0.10 but greater than or equal to 0.0033	Greater than 10 years but less than or equal to 300 years
Unusual (critical structures)	Less than 0.10 but greater than or equal to 0.00133	Greater than 10 years but less than or equal to 750 years
Extreme (normal structures)	Less than 0.0033	Greater than 300 years
Extreme (critical structures)	Less than 0.00133	Greater than 750 years

ECB 2017-2, Loading Condition Categories

A set of spreadsheets was developed in Mathcad to analyze the walls considering all applicable loading conditions. Concrete member sizes were designed based on all vertical, gravity, and horizontal forces acting on the structures. Figure 8 below provides a schematic of the different forces taken into consideration during the analysis.

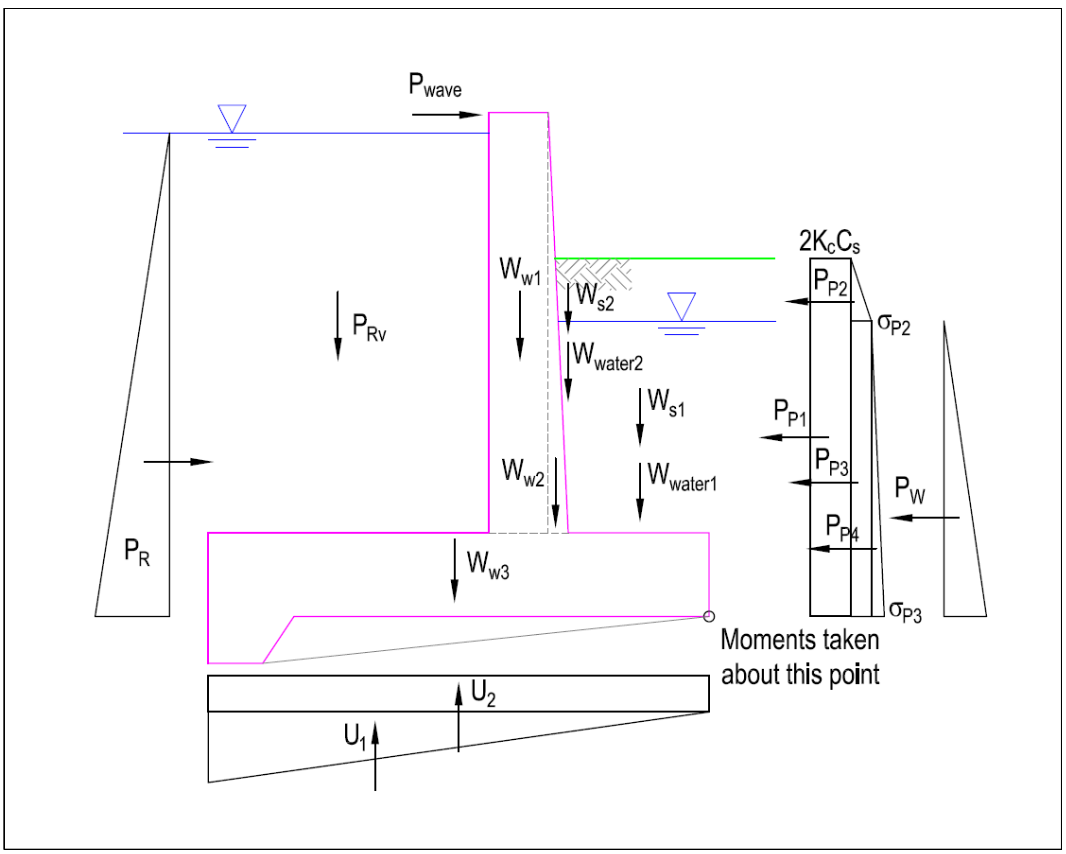

Figure 8 - Forces Acting on Floodwalls

The preliminary design results for T-wall types 1 and 2 are provided in Table 2 below.

Wall Type	Footing		Stem			Key	
	Width (ft)	Thickness (in)	Height (ft)	Thickness at Crest (in)	Thickness at Base (in)	Depth (ft)	Thickness (in)
1	11.5	18	8.2	12	18	2	12
2	6.67	14	5.2	10	14	1.5	12

Table 2 - T-wall Preliminary Design Results