US Army Corps of Engineers®
New York District

Shore-Based Measures Sub-Appendix

DRAFT

New York – New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study

Sub-Appendix B1

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Glossary

Term/Acronym	Expanded	Definition
ADCIRC model	ADvanced CIRCulation model	Computational model for predicting wind, wave, and storm surge conditions of tropical and extratropical cyclones
AdH Model	Adaptive hydraulics model	a high fidelity computational tool capable of simulating estuarine and riverine flows, hydrodynamics in reservoirs, and lakes, flows due to dam and levee breaches, continental scale flows, flows due to compound flooding, non-hydrostatic free surface flows, and all associated transport phenomenon.
ADM	USACE Agency Decision Milestone	
AEP	annual exceedance probability	the probability that at least one event in excess of a particular magnitude will occur in any given year
Aesthetic valuation		A judgement of value based on appearance of an object or emotional response.
AMM	USACE Alternatives Milestone Meeting	
ASA(CW)	Assistant Secretary of the Army (Civil Works)	an office of the United States Department of the Army responsible for overseeing the civil functions of the United States Army
ATR	Agency Technical Review	
BCR	benefit to cost ratio	
CBRA	Coastal Barrier Resources Act	
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	
CFR	Code of Federal Regulations	
closure criterion		The forecast water level for which operation of the storm surge barrier is authorized. For this study, this is assumed to be +7 feet NAVD 88
closure elevation		The observed water level at which the mechanical procedure to close storm surge barrier gates is executed

Term/Acronym	Expanded	Definition
CSO	Combined Sewage Outfalls	
CSRM	coastal storm risk management	
CZMA	Coastal Zone Management Act	
Deepwater ecoystems	Coastal ecosystems with bed elevation between -2m and -20m below Mean Sea Level (MSL)	
DOI	Department of Interior	an executive department of the U.S. Government responsible for the management and conservation of most federal lands and natural resources
DRSAA	Disaster Relief Supplemental Appropriations Act	
EFH	Essential Fish Habitat	
EIS	Environmental Impact Statement	
EJ	Environmental Justice	
elevation		The height of an object relative to an established datum such as mean sea level
EOP	Environmental Operating Principles	
EPA	Environmental Protection Agency	
EQ	environmental quality	
ERDC	U.S. Army Engineer Research and Development Center	
ESA	Endangered Species Act	
Estuarine Ecosystems	Coastal ecosystems with salinity from 0.5 to 28 ppt	
ESI	Environmental Sensitivity Index for shorelines from the National Oceanic and Atmospheric Administration	
FCSA	Fiscal cost share agreement	
FEMA	Federal Emergency Management Agency	
FIRM	Fire Insuranve Rate Map	
Freshwater Ecosystems	Coastal ecosystems with low salinity < 0.5 ppt	

Term/Acronym	Expanded	Definition
FWOP	future without project	
FWOPC	future without project condition(s)	
FWP	future with project	
FWPC	future with project condition(s)	
GIS	Geographic Information System	
HEC-FDA	Hydraulic Engineering Center Flood Damage Reduction Analysis	USACE software used to assess economic benefits of flood protection projects
height		A measurement from one fixed point to another fixed point
HFFRRF	high-frequency flood risk reduction features	
HR	Hudson River	
HTRW	Hazardous, Toxic, and Radioactive Waste	
HUC	Hydrologic Unit Code	
IFF	induced flooding mitigation feature[1]	Features used to offset the impacts of increased water levels due to the presence of a storm surge barrier
IMPLAN	IMpact analysis for PLANning	A software and database program that estimates input-output models based on data and assumptions of social accounting and multipliers.
Intertidal Ecosystems	Coastal ecosystems with bed elevation between Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW)	
IPCC	Intergovernmental Panel on Climate Change	
IPR	In-Progress Review	
IWR	Institute for Water Resources	
JB	Jamaica Bay	

[1] Formerly also referred to as induced flooding features.

Term/Acronym	Expanded	Definition
Marine Ecosystems	Coastal ecosystems with low salinity >= 28 ppt	
MBTA	Migratory Bird Treaty Act	
MHHW	Mean Higher High Water	The average of the higher high water height each tidal day observed over AdH simulation period
MLLW	Mean Lower Low Water	The average of the lower low water height each tidal day observed over AdH simulation period
MMPA	Marine Mammal Protection Act	
MSA	Magnuson-Stevens Fishery Conservation and Management Act	
MSL	mean sea level	
NACCS	North Atlantic Coast Comprehensive Study	
NAVD88	North American Vertical Datum of 1988	The vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations
NED	national economic development	
NEPA	National Environmental Policy Act	
NJ	New Jersey	
NJDEP	New Jersey Department of Environmental Protection	
NLT	no later than	
NMFS	National Marine Fisheries Service	
NNBF	Natural and nature-based feature	Landscape features that are used to provide engineering functions relevant to flood risk management, while producing additional economic, environmental, and/or social benefits Examples of NNBF include beaches and dunes; vegetated environments such as maritime forests, salt marshes, freshwater wetlands and fluvial flood plains, and seagrass beds; coral and oyster reefs, barrier islands, among others
NOAA	National Oceanic Atmospheric Administration	

Term/Acronym	Expanded	Definition
Nonstructural Measure		Permanent or contingent (deployable, or temporary) measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding.
NPS	National Park Service	
NWS	National Weather Service	
NY	New York (State)	
NYBEM	New York Bight Ecological Model	
NYC	New York City	
NYDOS	New York Department of State	
NYNJHAT	New York New Jersey Harbor and Tributaries	
NYNJHAT	New York New Jersey Harbor and Tributaries Study	
NYSDEC	New York State Department of Environmental Conservation	
OFC	Other first costs	
OHSIM	Oyster Habitat Suitability Index Model	
OMRR&R	Operations, Maintenance, Repair, Rehabilitation & Replacement	
OSE	other social effects	
PDT	project delivery team	
PED	preconstruction, engineering, and design	
ppt	parts per thousand	
RECONS	Regional ECONomic System	a model designed to provide estimates of regional economic impacts and contributions associated with Corps projects, programs, and infrastructure across Corps Civil Works business lines
RED	Regional economic development	
REMI	Regional Economic Model, Inc.	Input/output regional economic model
RRF	risk reduction feature[2]	features to reduce the residual coastal flood risk prior to closure of a given SSB

[2] Formerly also referred to as residual risk feature

Term/Acronym	Expanded	Definition
RSLC	relative sea level change	
S&A	State and Agency (Review)	
SAV	submerged aquatic vegetation	
SBM	shore-based measure	On-land perimeter measures such as levees, floodwalls, dunes, promenades, etc., that are constructed to impede coastal storm surge
SSB	storm surge barrier	In-water measure consisting of navigable and auxiliary gates which can be opened and closed to impede storm surge or tides from entering an area vulnerable to coastal flooding.
Still Water Overtopping		the amount of water flowing over the crest of a coastal structure such as a seawall, a dike, a breakwater, due to still water only
STP	Sewage Treatment Plant	
Structural Measure		Permanent measures that prevent or provide resistance to damage from flooding. Also called "grey infrastructure."
Subtidal Ecosystems	Coastal ecosystems with bed elevation between Mean Lower Low Water (MLLW) and -2m below Mean Sea Level (MSL)	
SWL	Still Water Level	Average water surface elevation at any instant, excluding local variation due to waves and wave set-up, but including the effects of tides, storm surges and long period seiches
TEU	Twenty-foot Equivalent Unit	a unit of cargo capacity generally used for container ships and container handling facilities
trigger elevation		
TSP	Tentatively Selected Plan	
US	United States	
USACE New York District	U.S. Army Corps of Engineers North Atlantic Division New York District	
USACE North Atlantic Division	U.S. Army Corps of Engineers North Atlantic Division New York District	

Term/Acronym	Expanded	Definition
USFWS	U.S. Fish & Wildlife Service	
USGS	U.S. Geological Survey	
VN	Verrazano Narrows	
VT	Vertical Team	USACE internal project team consisting of members across all three levels of USACE: district, division, and HQ
Wave Overtopping		the amount of water flowing over the crest of a coastal structure such as a seawall, a dike, a breakwater, due to wave action
Wave Runup		Wave run-up is the maximum onshore elevation reached by waves, relative to the shoreline position in the absence of waves
WPCP	Water Pollution Control Plant	
WRDA	water resources development act	a series of acts, usually biannual, which authorize funding for a variety of studies and projects, including beach nourishment, clean water, and flood control programs
WSE/WSEL	Water surface elevation	
WWTP	Wastewater Treatment Plant	

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1 Introduction

1.1 Project Overview

1.1.1 The Study

The North Atlantic Coast Comprehensive Study (NACCS) was conducted to address the flood risk to vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the North Atlantic Division of the U.S. Army Corps of Engineers (USACE). The New York/New Jersey Harbor and Tributaries (NYNJHAT) study area was identified as a "focus area" within the NACCS study.

The study purpose is to determine the feasibility of coastal storm risk management (CSRM) in the NYNJHAT study area and to recommend a plan that will contribute to community and environmental resilience.

The NYNJHAT study area encompasses the New York Metropolitan Area, including the most populous and densely populated city in the United States, and the six most populated cities in New Jersey. The shorelines of some of the NYNJHAT study area are characterized by low elevation areas, developed with residential and commercial infrastructure that are subject to coastal flood risk. The study area covers more than 2,150 square miles and comprises parts of 25 counties in New Jersey and New York. During coastal storms, storm surges are generated on the open coast and propagate through New York Harbor or through the Long Island Sound and flood the extensive low-lying areas surrounding the metropolitan area.

1.1.2 Organization of Engineering Analyses

The analysis and documentation of the engineering studies and analyses completed in support of the NYNJHAT Study are extensive. The Engineering Appendix to the Feasibility Study report discusses the engineering and design work conducted to lay out and evaluate potential structural and non-structural solutions to manage coastal storm risk in the study area.

A key component of the Feasibility Study (that is documented in the Engineering Appendix) is the preliminary layout for various coastal storm risk management measures. Structural measures, such as storm surge barriers, levees, floodwalls, seawalls, etc., and non-structural measures are included in the array of alternatives. The purpose of the structural measures is to form a flood risk reduction system and be an integral part of each alternative's coastal storm risk management strategy to impede storm surge propagation and reduce the risk of flooding for the area behind it.

The engineering appendix is limited to a description of structural measures and non-structural measures only, albeit that it is recognized that the study alternatives include more measures (i.e., Natural and Nature-Based Features). Specifically, the engineering appendix is organized around the principal distinction between storm surge barriers and shore-based measures. Storm surge barriers (SSBs) are large in-water, gated, navigable barriers, which are unique civil works on their own. However, shore-based measures (SBMs) are typical flood risk reduction features on land that combine to form a reach of the coastal storm risk management system. In other words, shore-based measures are the collective of all structural coastal storm risk management measures other than storm surge barriers.

This Shore Based Measures Sub-Appendix contains a technical description and narrative to support the preliminary design of the shore-based measures and includes documentation of the general design criteria of said measures. Furthermore, the sub-appendix is part of the engineering appendix that includes descriptions of engineering studies and analyses in support of the NYNJHAT Study, as laid out in Table 1-1. The reader is referred to the main Engineering Appendix for an overview of all engineering analyses and studies, and referred to the storm surge barrier sub-appendix for a detailed description of the design development of the storm surge barriers that are part of the study alternatives.

Table 1-1: NYNJHAT CSRM Feasibility Study Engineering Appendix and Sub-Appendices

Appendix	Sub-appendix	Contents/ Subject
Engineering Appendix		Engineering appendix to the Feasibility Study Report documenting preliminary designs of all structural measures that are part of this coastal storm risk management study
	SSB sub-appendix	Conceptual Design for Storm Surge Barriers that are part of the study alternatives, with emphasis on a conceptual design for the Verrazzano Narrows, Jamaica Bay, and Hackensack River Storm Surge Barrier
	SBM sub-appendix	The Structural Coastal Storm Risk Management (CSRM) shore-based measures evaluated as part of the Study

1.2 Shore-Based Measures Sub-Appendix Content

1.2.1 Scope

The scope of this sub-appendix is to introduce the shore-based measures, the location of the alignments, and selection of shore-based measures for each alignment. Furthermore, the content of this sub-appendix provides a narrative on the design development, presents the preliminary design of the individual measures, and provides quantity take-offs. This information is then used to develop cost estimates for the structural measures and the project alternatives, which is documented separately in the cost engineering appendix.

1.2.2 Shore-Based Measures – NYNJHAT Study Terminology

The six alternatives for the NYNJHAT Study (no action, and five project alternatives) presented in the body of the main feasibility report represent scales of solutions: system-wide, or basin-wide, or site-specific CSRM solutions. During project scoping, the basic outline of each of these alternatives was set and then refined during the feasibility study phase. Each study alternative, other than the no-action alternative and Alternative 5, consists of a flood risk reduction system that combines storm surge barriers and shore-based measures. Alternative 5 only included shore-based measures. Over the course of the feasibility study, two additional categories of measures were added to address two specific types of flood risk. These flood risks are:

1) Induced Flood Risk: This refers to an increase in flood levels as a result of the proposed project. For example, the presence of a structural measure that is part of an alternative (e.g., storm surge barrier) is an effective impediment to the storm surge but can cause peak storm surge levels to increase marginally on the ocean side of the storm surge barrier, compared to conditions without the presence of a storm surge barrier.

2) Residual Flood Risk: Residual flood risk in general is the flood risk that remains considering that the project reduces the flood risk but does not completely eliminate flood risk. In the context of the NYNJHAT Study, residual flood risk also specifically refers to the flood risk that remains for the coast lines "behind" the storm surge barriers. Storm surge barriers will only be closed for extreme events (an operating closure criterion will be set for each storm surge barrier – more details discussed in Section 3.1), and flood risk remains for the coastal areas served by the storm surge barrier up to the elevation of the closure criterion. As such, flood risk associated with more frequent coastal flood events remains for low-lying coastal areas behind a storm surge barrier because the storm surge barrier may not be operated for such events

As a result of the identification of these processes and the need to address them, Induced Flooding mitigation Features (IFFs) and Risk Reduction Features (RRFs) were introduced to address the two respective flood risk conditions identified above. Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs (to manage the risk of frequent flooding) and IFFs (to manage induced flooding) are also proposed, in an effort to provide an integrated solution.

To present one example, Figure 1-1 below shows the basic outline of the flood risk reduction system proposed for Alternative 2. The image shows storm surge barriers (Outer Harbor storm surge barrier, at the apex of the New York Bight, and the Throgs Neck storm surge barrier, at the western end of the Long Island Sound) and the shore-based measures that tie into them, jointly providing a system-wide flood risk reduction alternative. The yellow shaded area highlights the area where, as a result of the project, IFFs need to be considered (see also Annex B), The blue shaded area highlights the new basin area for which the need for RRFs is evaluated. A detailed description of the study alternatives and similar maps for all study alternatives are provided in the section hereafter.

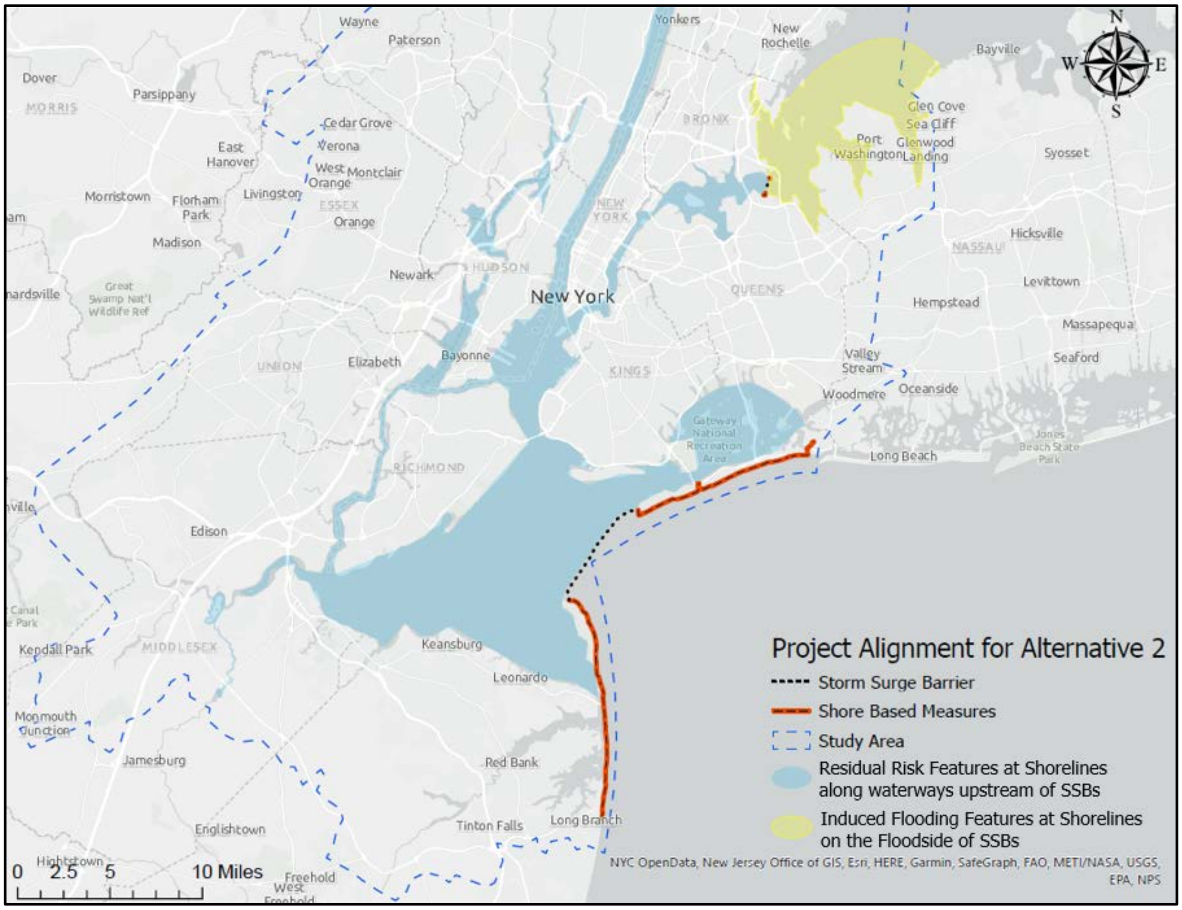

Figure 1-1: Structural measures that form the basis for Alternative 2 and areas where the need for RRFs and IFFs[3] is evaluated.

As a result, the NYNJHAT Feasibility Report includes the terms SBM, IFFs, and RRFs when describing structural coastal storm risk management measures at the shoreline or on land. A brief description of each acronym and the flood risk associated with each is provided in Table 1-2 below.

Table 1-2: Shore-Based Measures Terminology

Acronym	Term	Description	Design Event
SBM	Shore-Based Measure	SBMs are designed to provide flood risk reduction for 100-year Return Period (RP) storm events (1% Annual Exceedance Probability (AEP)) in 2095 for areas that are not protected by storm surge barriers. The alignments of SBMs (as defined in Section 1.2) for each study alternative was developed by USACE, during plan formulation, with further modifications and refinements made over the course of the feasibility study phase where appropriate.	1% AEP flood level

[3] A more detailed description of induced flooding and the areas affected by this process is provided in section 3.1

Acronym	Term	Description	Design Event
IFF	Induced Flooding mitigation Feature	IFFs are equal and equivalent to SBMs and are only distinguished as IFFs because they provide flood risk reduction for areas subject to induced flooding.	1% AEP flood level
RRF	Risk Reduction Feature	Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary measures to manage the risk of frequent flooding are also proposed. RRFs mitigate residual flood risk under the assumption that the storm surge barrier (SSB) closure criterion is El. +7 ft NAVD88.	Up to the +7ft NAVD88 flood level

1.3 Overview of NYNJHAT Study Alternatives

1.3.1 NYNJHAT CSRM Feasibility Study Alternatives

The NYNJHAT Study Alternatives were developed by the USACE New York District (USACE-NAN) during the plan formulation phase and refined during the feasibility study. Alternative 1 is a no-action alternative; the alternatives 2, 3A, 3B, and 4 included storm surge barriers and shore-based measures. Alternative 5 includes only shore-based measures. The definition of the SBM types is provided in Table 1-2. The study alternatives are further described below and shown in Figure 1-1 to Figure 1-5. These figures present the locations of the SSBs and SBMs, but only the areas of interest that were analyzed for the placement and inclusion of RRFs and IFFs. Section 3.1 provides more detail on the location of RRFs and IFFs. Lastly, detailed maps depicting the alignments and structural measures of each study alternative are included in Annex D.

1.3.2 Alternative 1

Alternative 1 is a no-action alternative. Alternative 1 does not incorporate any structural measures.

1.3.3 Alternative 2

Alternative 2 incorporates SBMs in combination with the Outer Harbor storm surge barrier connecting Sandy Hook, New Jersey to Rockaway Point on the Rockaway Peninsula, as well as the storm surge barrier at Throgs Neck. To mitigate the residual flood risk, RRFs are proposed along the shorelines of the Lower and Upper Bay, the Arthur Kill region, the Raritan River, Jamaica Bay, the Hackensack River and Passaic River, and the Lower Hudson and East Rivers. Induced flooding is expected to occur in the western end of the Long Island Sound as a result of the presence of the Throgs Neck storm surge barrier; thus, IFFs are proposed in this region. A schematic overview of the structural coastal storm risk management measures for this Alternative is shown in Figure 1-1.

1.3.4 Alternative 3A

Alternative 3A integrates SBMs with the storm surge barriers at Verrazzano-Narrows, Arthur Kill, Throgs Neck, and Jamaica Bay. To mitigate the residual flood risk, RRFs are proposed along the shorelines of the Upper Bay, the Arthur Kill region, Jamaica Bay, the Hackensack River, Passaic

River, the Lower Hudson and East River. Induced flooding is expected to occur along the Lower Bay, the Raritan River, and the western end of Long Island Sound as a result of the presence of the above-stated storm surge barriers; thus, IFFs are proposed in these regions. The schematic concept for this Alternative is shown in Figure 1-2.

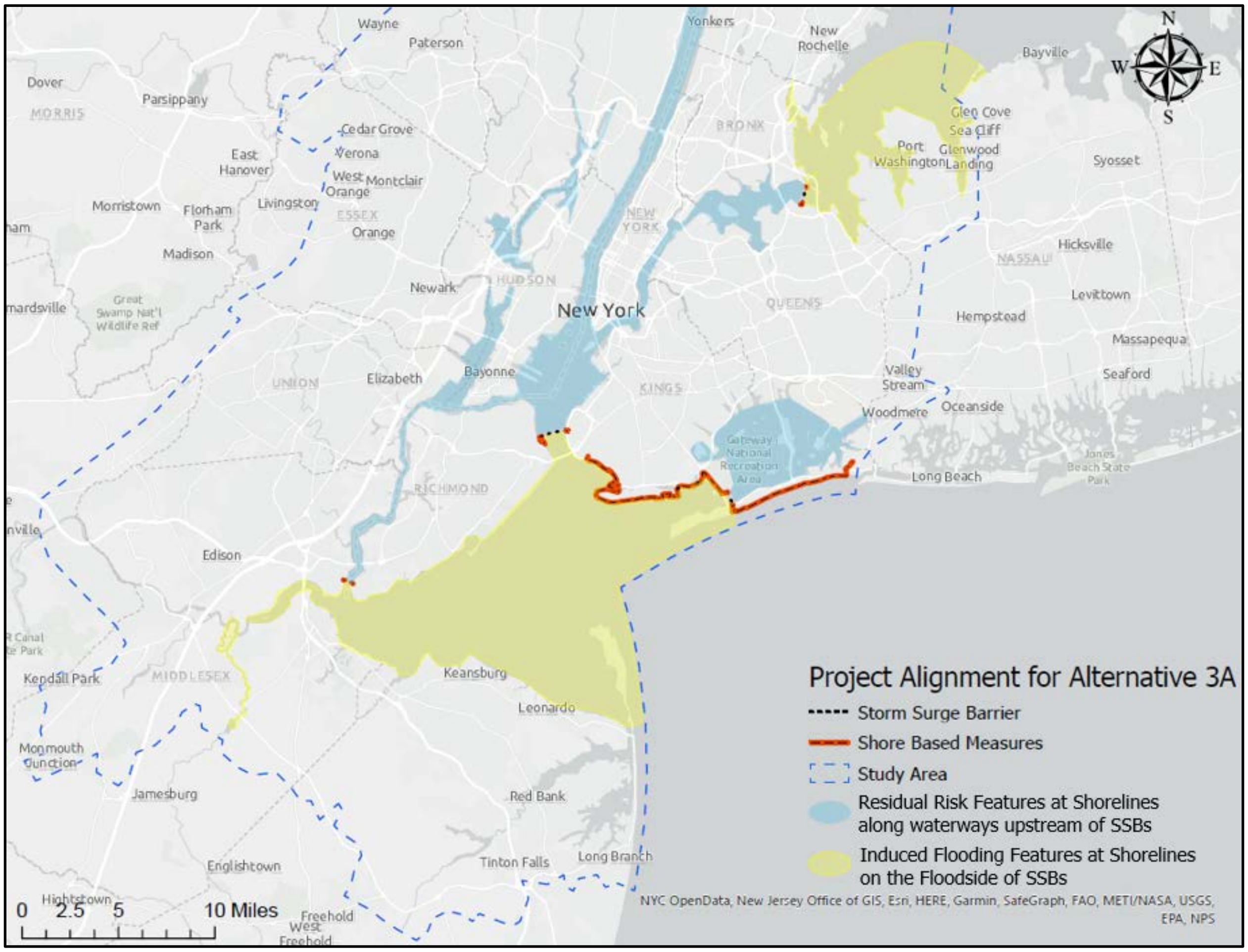

Figure 1-2: Structural measures that form the basis for Alternative 3A and areas where the need for RRFs and IFFs is evaluated

1.3.5 Alternative 3B

Alternative 3B integrates SBMs along with the Arthur Kill, Kill Van Kull, Jamaica Bay, Newtown Creek, Gowanus Canal, and Flushing Creek storm surge barriers. The required SBMs include risk reduction of the New Jersey Upper Bay and Hudson River shoreline from Liberty State Park to Hoboken; New York City West Side shoreline from the Brooklyn Bridge to Pier 78; East Harlem shoreline from Carl Schurz Park to Washington Heights; the Red Hook shoreline; and the Long Island City-Astoria shoreline from WNYC Transmitter Park to Ed Koch Queensboro Bridge. To mitigate the residual flood risk, RRFs are proposed along the shorelines of Newark Bay, the Arthur Kill region, Jamaica Bay, and the Hackensack and Passaic Rivers. Induced flooding is expected to occur in portions of the East River and Harlem River and on the flood side of the Jamaica Bay storm surge as a result of the presence of the above-stated storm surge barriers; thus, IFFs are suggested to be placed in these regions. A schematic concept for this Alternative and the referenced reaches is shown in Figure 1-3.

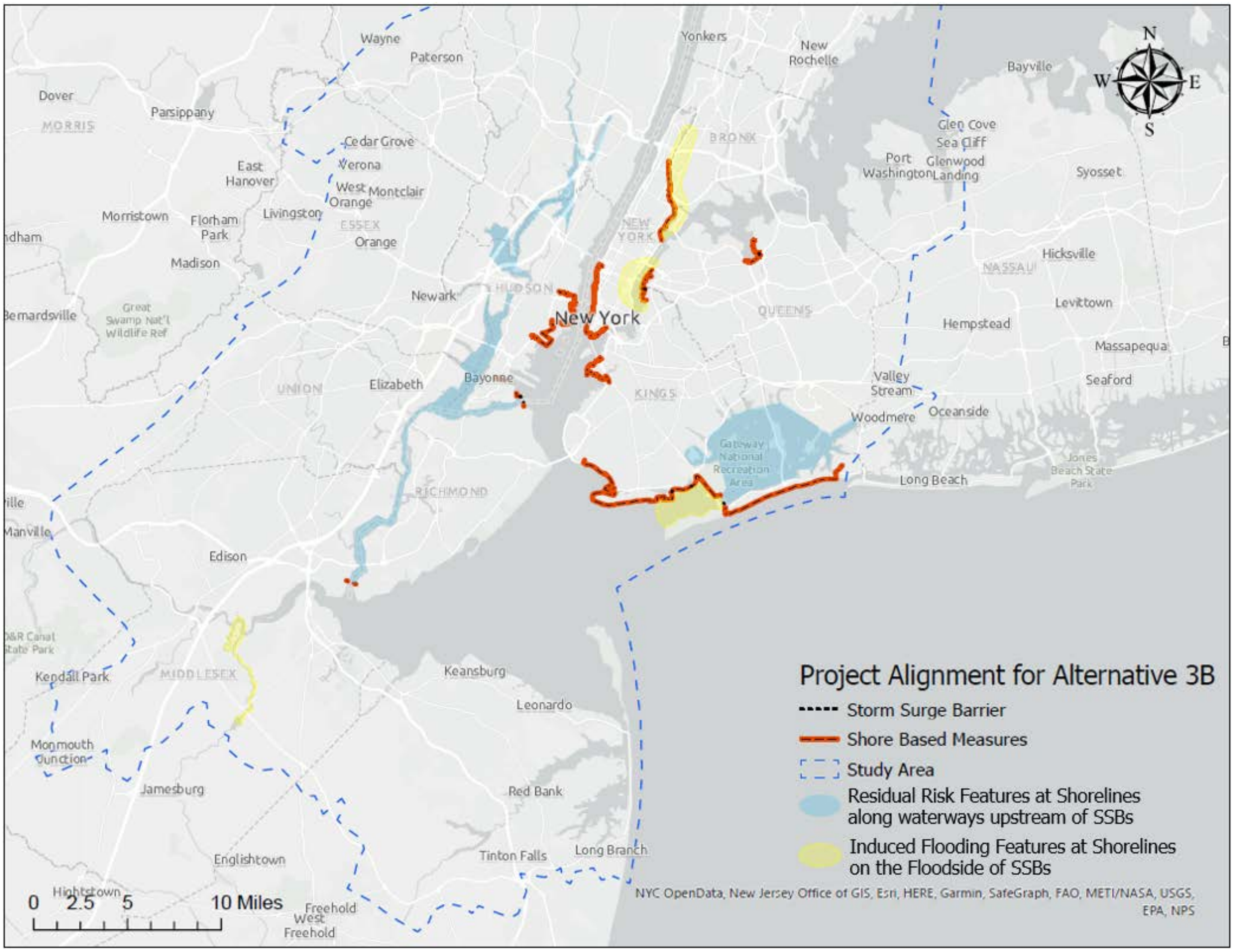

Figure 1-3: Structural measures that form the basis for Alternative 3B and areas where the need for RRFs and IFFs is evaluated

1.3.6 Alternative 4

Alternative 4 incorporates SBMs along with the storm surge barriers at Jamaica Bay, Newtown Creek, Gowanus Canal, Flushing Creek, and Hackensack River. These SBMs are located at the Hackensack River and along the Hudson River shoreline from Liberty State Park to Hoboken; New York City West Side shoreline from Brooklyn Bridge to Pier 78; Long Island City shoreline; the Red Hook shoreline, the Flushing Creek shoreline; and the East Harlem Shoreline from Carl Schurz Park to Washington Heights. To mitigate the residual flood risk, RRFs are proposed along the shorelines of Jamaica Bay. Induced flooding is expected to occur in Newark Bay and portions of the Arthur Kill and Kill van Kull, and on the flood side of the Jamaica Bay storm surge barrier; thus, IFFs are suggested to be placed in these regions. A schematic concept for this Alternative is shown in Figure 1-4.

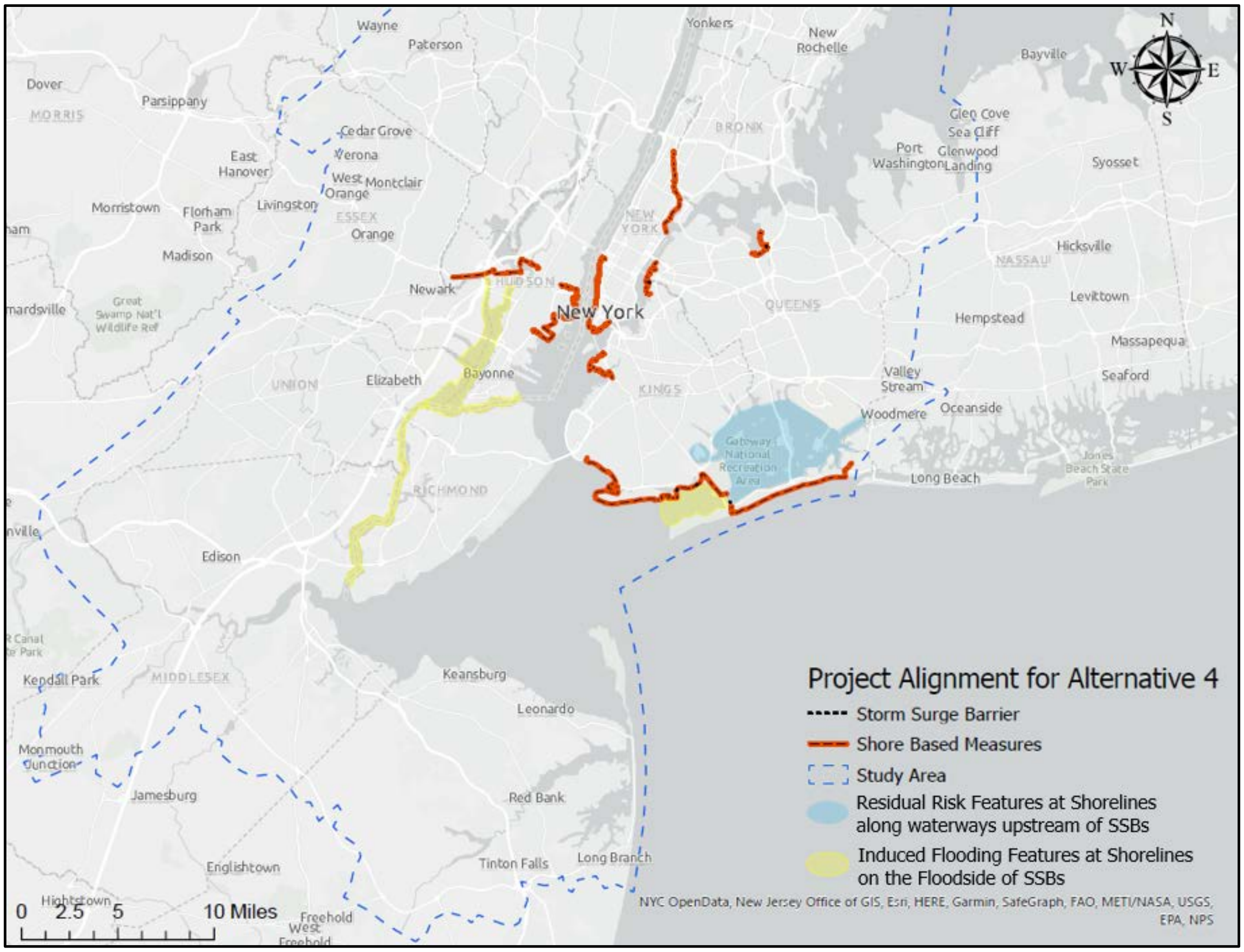

Figure 1-4: Structural measures that form the basis for Alternative 4 and areas where the need for RRFs and IFFs is evaluated

1.3.7 Alternative 5

Alternative 5 presents a perimeter risk reduction concept which excludes storm surge barriers that traverse waterways or waterbodies. SBMs would be implemented at the New Jersey Upper Bay and Hudson River shoreline, New York City West Side shoreline, East Harlem shoreline, and the Hackensack Perimeter Lower, Middle, and Upper Areas. Due to the absence of storm surge barriers, IFFs and RRFs are not part of this alternative. A schematic concept for this Alternative is shown in Figure 1-5.

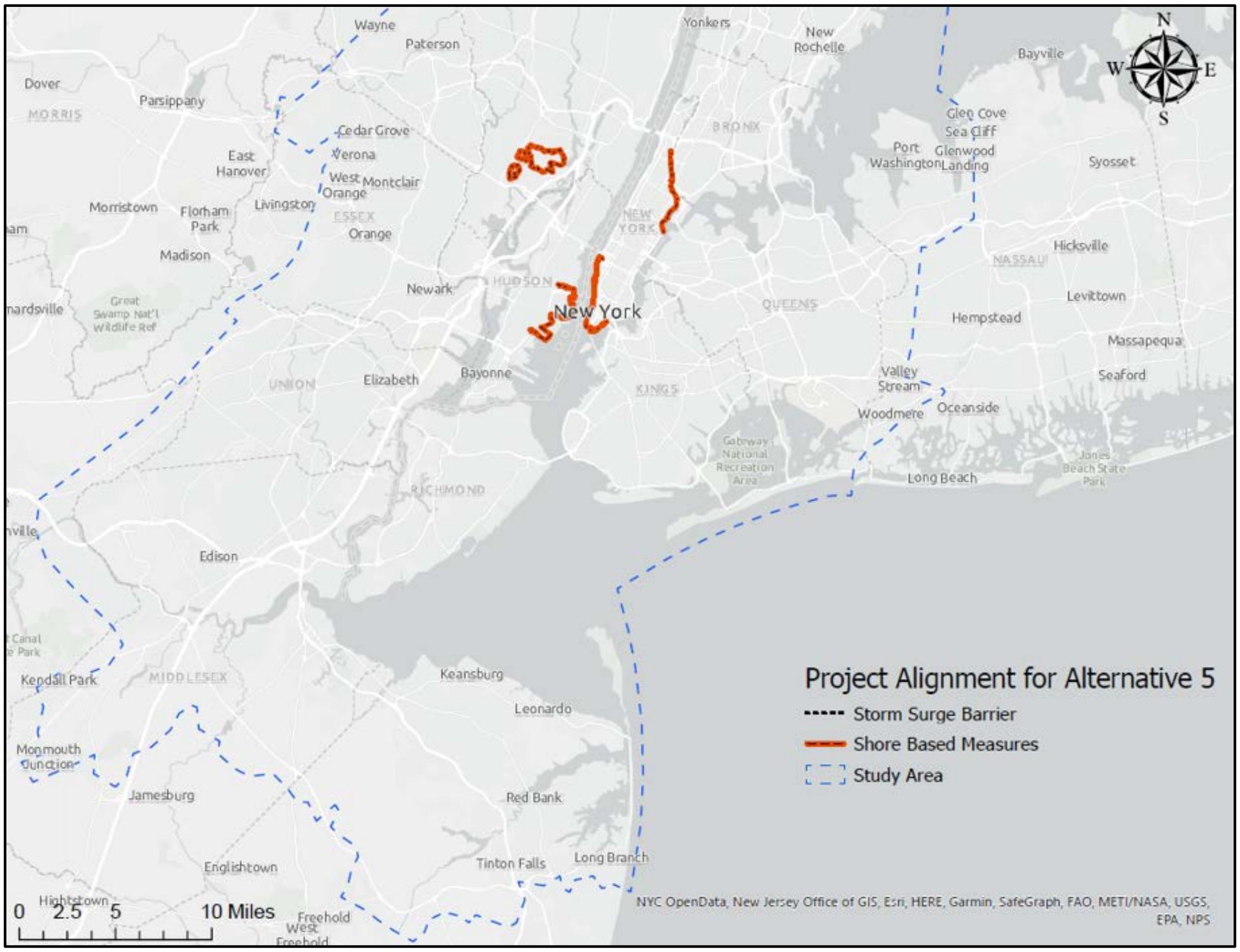

Figure 1-5: Structural measures that form the basis for Alternative 5

1.3.8 Overview of SBM Alignments

Several alternatives share the same SBM alignments. For example, the East Harlem SBM is included within Alternatives 3B, 4, and 5. Figure 1-6 provides a complete overview of all SBM alignments considered. However, the Northern and Southern extents of the study area are not shown due to the scale of the map. Table 1-3 provides an overview of all NYNJHAT Study Alternatives and reaches that include SBMs.

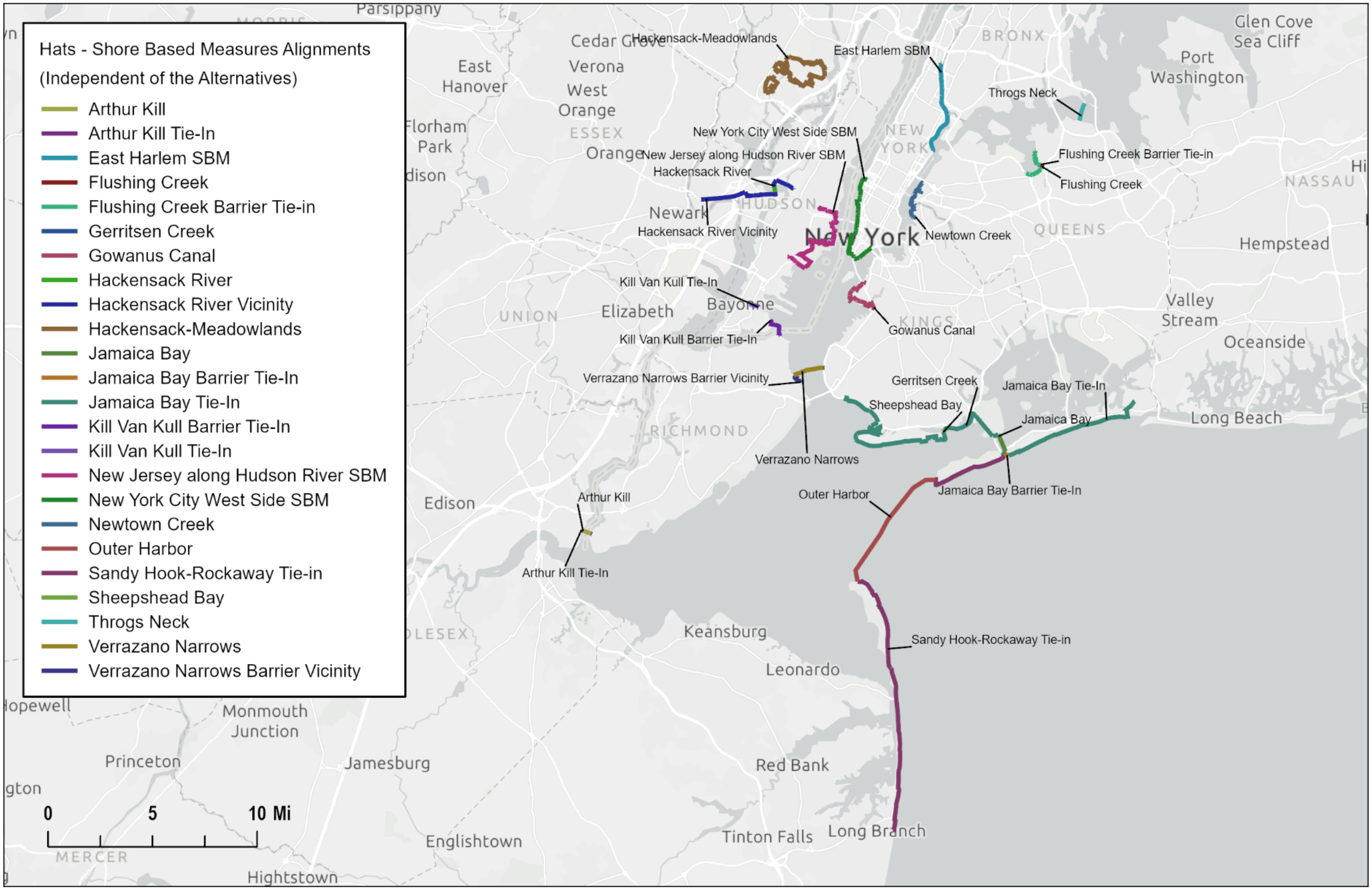

Figure 1-6: Overview of Reaches that include SBMs

Table 1-3: Overview of SBM Reaches and Inclusion per NYNJHAT Study Alternative

Name of Shore Based Measures Alignment	NYNJHAT Study Alternative				
	2	**3A**	**3B**	**4**	**5**
Arthur Kill Barrier Tie-In	No	Yes	Yes	No	No
East Harlem SBM	No	No	Yes	Yes	Yes
Flushing Creek Barrier Tie-in	No	No	Yes	Yes	No
Gowanus Canal Barrier Tie-in	No	No	Yes	Yes	No
Hackensack Perimeter Lower Area - Polygon	No	No	No	No	Yes
Hackensack Perimeter Middle Area - Polygon	No	No	No	No	Yes
Hackensack Perimeter Upper Area - Polygon	No	No	No	No	Yes
Hackensack River Barrier Tie-in	No	No	No	Yes	No
Jamaica Bay Barrier Tie-In	Yes	Yes	Yes	Yes	No
Kill Van Kull Barrier Tie-In	No	No	Yes	No	No
Kill Van Kull Barrier Tie-In Separated	No	No	Yes	No	No
New Jersey along Hudson River SBM	No	No	Yes	Yes	Yes
New York City West Side SBM	No	No	Yes	Yes	Yes
Newtown Creek Barrier Tie-in	No	No	Yes	Yes	No
Sandy Hook-Rockaway Barrier Tie-in	Yes	No	No	No	No
Throgs Neck Barrier Tie-in	Yes	Yes	No	No	No
Verrazzano Narrows Barrier Tie-in	No	Yes	No	No	No

1.4 Limitations and Reader's Guide

The purpose of the study was to develop preliminary SBM, RRF, and IFF designs that are comprehensive enough to be applicable for the realm of conditions found throughout the study area yet not too detailed or site-specific that they could only be applied at one location. Due to the vast area covered by the NYNJHAT study, generalized assumptions were made about existing conditions, such as site topography, bathymetry, and soil parameters. It is emphasized that no site-specific topographic survey, bathymetric survey, site condition survey, and/or geotechnical analyses have been completed. Instead, publicly available qualitative data, past relevant regional project experience and results from desktop analyses were used to develop preliminary SBM designs.

Based on a quantity per linear foot for each SBM, the SBM quantities for each Alternative werealternative was calculated. This information was then used as basis for cost estimates of the NYNJHAT Study Alternatives and is discussed in the Cost Appendix. This appendix focuses solely on the development of the preliminary designs, an inventory of measures per NYNJHAT Study Alternative, and a quantity take-off per measure. Cost estimates are covered in the Cost Engineering Appendix and hence not discussed herein.

Section 1.1 (above) provides an overview of the Project, while Section 2 provides the generalized design criteria used for the development of the SBMs. Section 3 provides the preliminary design for the SBMs developed for the NYNJHAT Study, and Section 4 provides the inventory of SBMs for all NYNJHAT Study Alternatives. The listed design criteria and preliminary designs are based on qualitative data and desktop level analysis analogous with the level of detail commensurate of a feasibility study and USACE's SMART planning principles. In instances where limited data was available, assumptions were made based on engineering judgment, previous experience, and/or the partial data that had been collected over the course of the feasibility study phase. The implications of such assumptions along with recommendations for further data collection and refined analysis to support refined designs post-Tentatively Selected Plan (TSP) are described in Section 5.

2 Generic Design Criteria

2.1 Introduction

As part of advancing preliminary designs for the SBMs, several criteria need to be established and defined. These criteria are defined quantitatively where possible, or qualitatively otherwise. Due to the size of the study area and the varying site conditions for all locations where the SBMs are proposed as part of the NYNJHAT Alternatives; the following criteria should not be seen as comprehensive, all-encompassing, or complete. Instead, the requirements and criteria form the basis for an iterative design approach, for which this feasibility study represents the first phase. Decisions and assumptions that may impact final design are emphasized and, where possible, a discussion is included for issues that need to be addressed in the risk register and or addressed in future phases as the project and the designs for the SBMs advance.

2.2 System of Units and Reference

U.S. customary units shall be used.

All elevations throughout the report are referenced to NAVD88 Geoid12B vertical datum in feet unless otherwise stated. The horizontal datum shall be the North American Datum of 1983 (NAD83) State Plane.

2.3 Service Life

The SBMs have various project components for which Life Cycle Design should be considered (ER 1110-2-8159). At this stage of the project (feasibility study), no such analysis has been performed; however, a project service life of 50 years is preliminarily recommended as a result of the size and nature of the project. The project will perform to meet the design criteria related to risk reduction in this document for a 50-year period spanning the years between 2045 and 2095. The project is to be designed for sea level rise, regional subsidence, and local settlement occurring for 50 years, assuming project construction completion in 2044. After such a time, to continue to achieve the same level of risk reduction, the structures would likely have to be adapted. Adaptive management may be necessary or structural improvements may be needed if the observed sea level rise exceeds the planning criteria.

2.4 Basic Functionality Requirements

The following functional requirements have been identified for the design of the SBMs consistent with the overall objectives of the NYNJHAT Study:

1. The SBMs shall be designed to reduce the risk of coastal storm damage for the area; in particular:
    a. The SBM shall reduce the risk associated with a 1% AEP coastal flood event including intermediate SLR up to the end of the service life.

b. The IFFs shall manage flood risk in areas where the 1% AEP flood risk is altered as a result of the proposed SSBs.

c. Whereas the RRFs shall mitigate residual flood risk for a flood level of +7 ft NAVD88 for the areas upstream of the storm surge barriers' closure;

2. The measures shall seek to minimize adverse effects on existing infrastructure in the study area;

3. The measures shall seek to minimize adverse effects on existing access and egress, such as access to existing private and public open spaces; and

4. The measures shall seek to minimize footprint and impact to the environment.

2.5 Design Standards, Codes, and Guidelines

The following codes, references, and standards were used as a basis for the design of the SBMs:

1. American Association of State Highway and Transportation Officials (AASHTO). *Standard Specifications for Highway Bridges, 17th Edition.*
2. AASHTO. Load and Resistance Factor Design (LRFD) Bridge Design Specifications, Customary U.S. Units, 6th Edition.
3. American Concrete Institute (ACI). ACI SPEC-301-20: Specifications for Concrete Construction.
4. ACI. ACI 350-20 Code Requirements for Environmental Engineering Concrete Structures.
5. ACI. ACI 318-14 Building Code Requirements for Reinforced Concrete.
6. American Institute of Steel Construction (AISC). Manual of Steel Construction, Load and Resistance Factor Design (LRFD), 14th Edition.
7. American Society of Civil Engineers (ASCE). ASCE 24-14 Flood Resistant Design and Construction.
8. ASCE. ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures.
9. American Welding Society (AWS). ANSI/ AWS D1.1-2010 Structural Welding Code – Steel.
10. Construction Industry Research and Information Association (CIRIA), The Rock Manual, 2007.
11. Federal Emergency Management Agency (FEMA). Guidance for Flood Risk Analysis and Mapping – Coastal Structures, November 2015.
12. International Code Council (ICC). International Building Code (IBC), 2021.

13. Office of the Federal Register. Code of Federal Regulations (CFR) – 44 CFR 65.10.
14. United States Steel (USS). U.S. Steel Sheet Piling Design Manual, 1984.
15. United States Army Corps of Engineers (USACE). HSDRRSDG Hurricane and Storm Damage Risk Reduction Design Guidelines with June 2012 updates.
16. USACE. Engineer Circular (EC) 1110-2-6067 USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation.
17. USACE. Engineer Manual (EM) 1110-2-1100 Coastal Engineering Manual.
18. USACE. Engineer Manual (EM) 1110-2-1614 Design of Coastal Revetments, Seawalls and Bulkheads.
19. USACE. Engineer Manual (EM) 1110-2-1913 Design and Construction of Levees.
20. USACE. Engineer Manual (EM) 1110-2-2100 Stability Analysis of Concrete Structures
21. USACE. Engineer Manual (EM) 1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures.
22. EM 1110-2-2503 (Design of Sheet Pile Cellular Structures Cofferdams and Retaining Structures)
23. USACE. Engineer Manual (EM) 1110-2-2504 Design of Sheet Pile Walls.
24. USACE. Engineer Manual (EM) 1110-2-2906 Design of Pile Foundations.
25. USACE. Engineer Regulation (ER) 1100-2-8162 Incorporating Sea Level Change in Civil Works Programs.
26. USACE. Engineer Engineering Technical Letter (ETL) 1110-2-58 Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, And Appurtenant Structures.
27. USACE. Engineer Engineering Technical Letter (ETL) 1110-2-2105 Design of Hydraulic Steel Structures.

2.6 Site Conditions

2.6.1 Bathymetry and Topography

The site conditions for all SBM locations were assessed using existing nautical charts in combination with flood extent maps, aerial maps, LiDAR data (USGS, 2014), and land use maps that were readily available within the public domain.

2.6.2 Geology and Geotechnical

2.6.2.1 Geology

The shore-based measures on the south and east of the project area are generally located in a geological, structural, and topographic province known as the Atlantic Coastal Plain. In this area, the Coastal Plain consists of unconsolidated deposits of sands, silts, and clays that gently dip seaward. The coastal plain deposits are typically overlain with younger glacial deposits of till, outwash material, and moraine deposits. More recent deposits of fill, stream material, and reworked sediments may overlie the glacial deposits.

In the west regions of the project area, SBMs are located along waterways within the Newark Basin, a partial rift which has been filled with sand, silt, and clay sediment eroded from the surrounding basin walls and hills of the Piedmont region.

SBMs within the northern regions of the project area are located along waterways within the Manhattan Prong geologic formation. This area typically consists of metamorphic bedrock overlain by recent alluvial deposits of sand, silt, and clay.

2.6.2.2 Geotechnical

No site-specific geotechnical investigation or analysis was completed as part of this study. It should be emphasized that preliminary SBMs are not site-specific but are expected to be used throughout the study area as part of any of the NYNJHAT Study Alternatives. However, for SBMs other than the reinforced dunes, geotechnical analysis and data reported in the *Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet Draft Hurricane Sandy General Revaluation Report Engineering Appendix* (USACE 2016) was used for indicative soil conditions. Generally, the soils are classified as fine to medium grained, poorly graded sand classified as “SP” by the Unified Soils Classification System with a saturated unit weight of 120 pcf and a friction angle of 33 degrees. The soil conditions are for the Jamaica Bay area and are judged to be a reasonable representation of potential soil conditions throughout the NYNJHAT study area. Since the NYNJHAT Study area is expected to have deposits of alluvium, consisting of mainly granular deposits, the soil assumption is reasonably representative for structures located along the waterfront and adequate for this level of study.

For the reinforced dunes, the assumed geotechnical conditions were taken from *FINAL Integrated Hurricane Sandy General Reevaluation Report and Environmental Impact Statement Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Appendix A1* (USACE 2018a).

2.6.3 Tides and Water Levels

Where applicable tidal information from NOAA station 8531680 – Sandy Hook, NJ, is used to inform the design of the SBMs. The tidal datums are summarized in Table 2-1.

Table 2-1: Tidal Datums for NOAA Station 8531680 (Sandy Hook, NJ)

Tidal Datum	Abbreviation	NAVD88 (ft)	MLLW (ft)
Highest Observed 10/29/2012 (Hurricane Sandy)	Max Tide	9.21	12.03
Highest Astronomical Tide	HAT	3.76	6.58
Mean Higher-High Water	MHHW	2.41	5.23
Mean High Water	MHW	2.08	4.9
Mean Sea Level	MSL	-0.24	2.58
Mean Low Water	MLW	-2.62	0.2
Mean Lower-Low Water	MLLW	-2.82	0
Lowest Astronomical Tide	LAT	-4.19	-1.37
Lowest Observed 2/2/1976	Min Tide	-7.53	-4.71

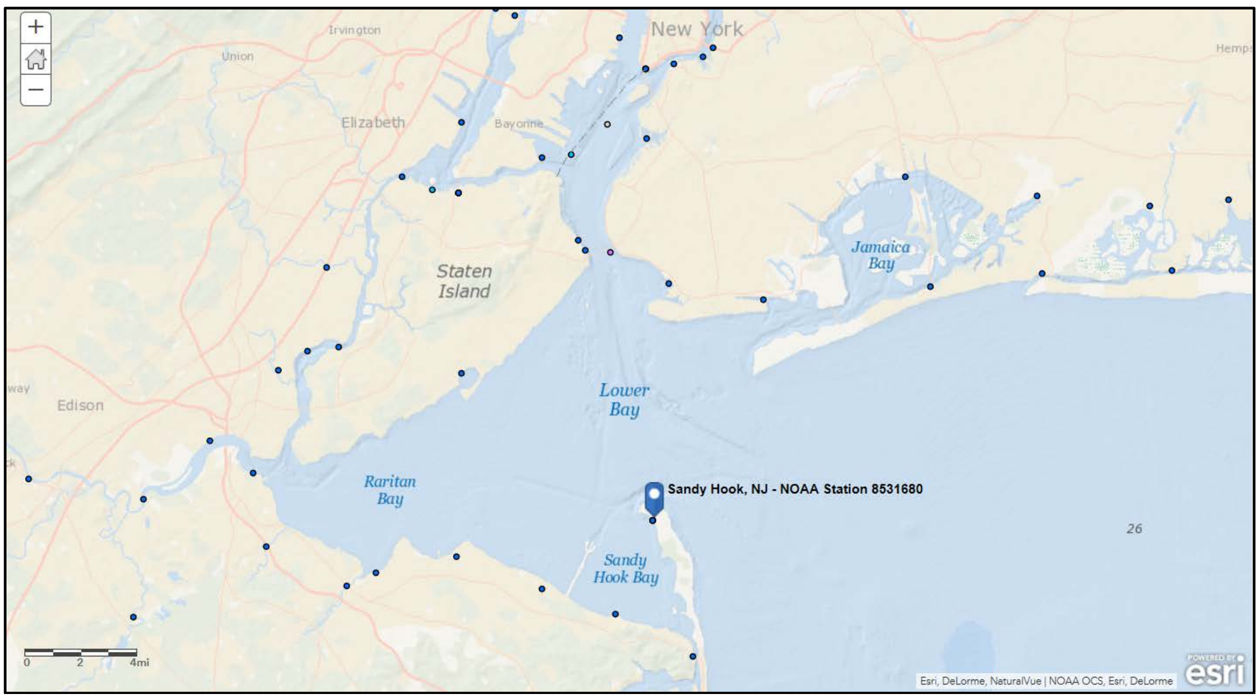

Figure 2-1: NOAA Station Sandy Hook, NJ

2.6.4 Sea Level Change

The NYNJHAT Study uses the USACE intermediate scenario for relative sea level change (RSLC). RSLC is included in the design of the SBMs and, due to the wide geographic distribution of SBMs throughout the study area, RSLC is based on the most conservative values gathered from the NOAA stations within the study area. The Sandy Hook gauge has the highest predicted sea level change values. The USACE intermediate scenario from 1992 (base year) to 2045 (start of service life) and from 1992 to 2095 (the end of the service life) were used to develop the sea level change values as shown in Table 2-2.

Table 2-2: Sea Level Change per ER 1100-2-8162 (USACE) in feet

Sea Level Change per the USACE Intermediate Scenario	1992 (Base Year)	2045	2095
Station 8561680, Sandy Hook	0	0.94	2.29

2.6.5 Extreme Still Water Level (SWL)

The extreme still water levels (SWLs) vary across the HAT Study Area. The results from the North Atlantic Coast Comprehensive Study (NACCS), completed by USACE in 2015, include the computed water-level statistics corresponding to different confidence intervals based on the Advanced Circulation (ADCIRC) model data, and are used to inform the design water levels for this study. The design SWL is based on a 1% AEP with a 50% confidence limit (CL) adjusted to include SLC to the end of the service life using USACE intermediate SLC scenario as discussed in Section 2.6.4. The extracted SWLs within the project area (future "without-project" conditions) are shown in Figure 2-2 below.

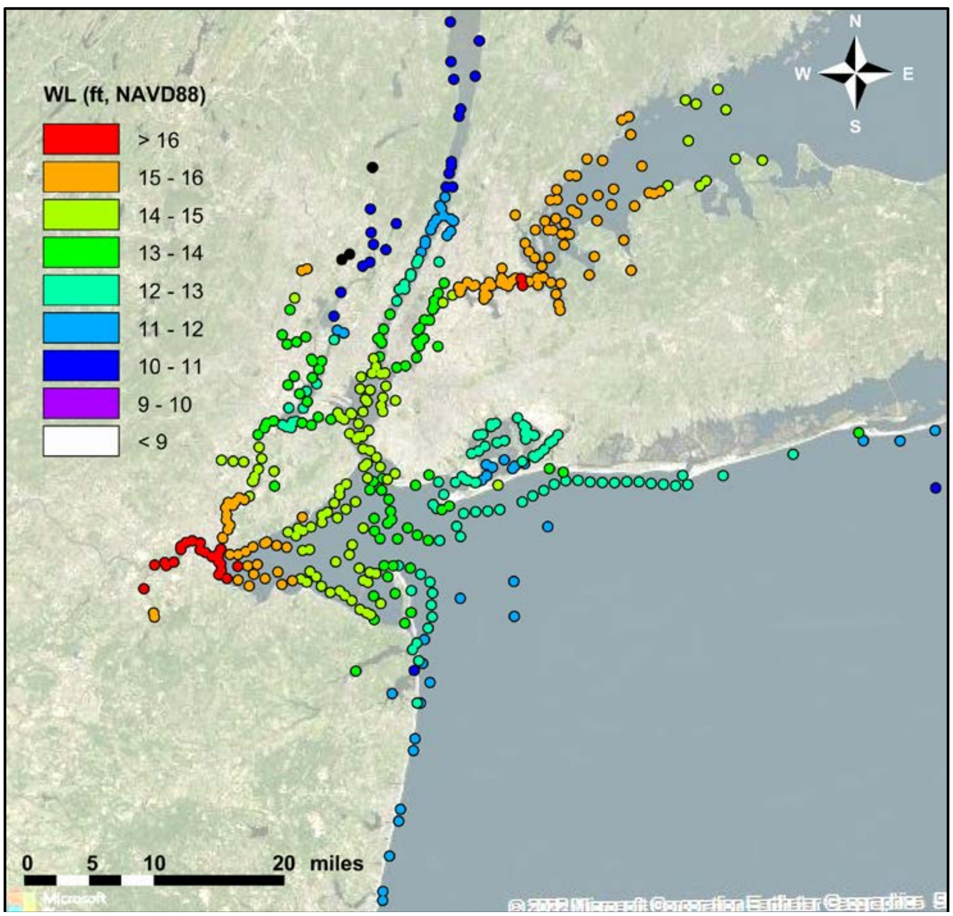

Figure 2-2: Still water levels extracted from the NACCS – Future without-project conditions, 1% AEP still water level in 2095 (50% confidence limit)

It is recognized that the SWL varies throughout the study area, and SBM crest elevations take this spatial variability into account (see Annex C). For the load combinations used for the preliminary design of the SBMs, this spatial variation is temporarily omitted and a representative average value for both the SWL and wave conditions are selected. This assumption allows the structural SBM designs to be based upon conservative loading assumptions and be implementable at all coastal edges throughout the study area. At the same time, this assumption allows the team to limit the number of variations of SBM designs (i.e., no separate designs are needed for each location where wave and SWL conditions vary). The design 1%, 0.2%, and 0.133% AEP SWLs for the SBMs are summarized in Table 2-3.

Table 2-3: 1%, 0.2% and 0.13% AEP Still Water Levels (Representative Value) inclusive of Sea Level Rise

AEP	Return Period (years)	Design Still Water Level (ft NAVD88)
1%	100	15.0*
0.2%	500	18.0*
0.133%	750	20.0*
*The representative values correspond to year 2105 conditions, because the period of analysis for the NYNJHAT Study spanned the years 2055 through 2105 in an earlier phase of the study. This introduces conservatism in the water level values since an additional 10 years (2095 through 2105) of sea level rise is inadvertently accounted for. These values include SLC to 2105. The base SWLs are based on the NACCS stage frequency curves which are referenced to 1992 sea levels.		

2.6.6 Extreme Wave Heights and Periods

The expected significant wave heights for the 1% AEP and 0.2% AEP were derived separately for each measure based on nearshore wave transformation of the corresponding NACCS statistics; see also Holthuijsen et al., 1996. The average of the wave height and period at all measures of the same type was adopted as input for load calculations for that measure type. SBMs were designed for the wave loading in combination with the SWL conditions with the same AEP. The process used to establish design waves at the 1%, 0.2%, and 0.133% AEP for the various measure types, and tables with the derived wave characteristics for each measure type are provided in Annex C.

2.6.7 Overtopping and Freeboard Requirements

<u>SBMs</u>

Two overtopping performance criteria were used to determine the structural elevations for the SBMs and IFFs. For all SBMs, with the exception of the reinforced dune[4], an overtopping criterion of 1.08 x 10^{-2} cubic foot per second per foot (cfs per foot) or 1 liter per second per meter (l/s/m) at

[4] The reinforced dune crest elevation was set based on prior studies for the Rockaway, NY, shorefront, see also section 3.6.6.

the 90% statistical confidence limit is set to determine the structure height. This criterion is applied at the end of the project service life. To determine the required freeboard for the given overtopping criterion, the design 1% AEP SWL and 1% AEP waves as discussed in Section 2.6.5 and Section 2.6.6, respectively, were used. The analysis for the freeboard calculation is described in further detail in Annex C.

In addition, a resiliency check was included for the SBMs and IFFs such that the structure elevation is equal to or above the 0.2% AEP (500-year) SWL.

RRFs

For the RRFs, the design water level is determined by the closure criterion of the storm surge barriers, which is +7 ft NAVD88. All RRF crest elevations were set at +10 ft NAVD88 and thus all RRFs have a uniform 3 ft freeboard. This freeboard would satisfy the adopted overtopping criteria for up to a 2 ft wave (of 3 sec period) impacting a vertical wall in most cases. No separate in-depth analysis of potential wind-generated waves at the design level of the RRFs was conducted. However, due to the sheltered location of RRFs, within a basin behind a storm surge barrier, the 100-year wave heights are expected to be smaller on average than at the SBMs, and likely smaller than or comparable to 2 ft in most cases. It is therefore expected that the adoption of a uniform 3-ft freeboard may also provide some buffer where the wave-heights are small, against potential variations in the design water level and fluctuations of the basin water level when the storm surge barrier is closed. A more detailed analysis of RRF crest heights for the selected plan is recommended for the next phase of the study.

The closure criterion of +7ft NAVD88 has preliminarily been established for all storm surge barriers in the NYNJHAT Study. This allows for consistent evaluation of the storm surge barriers across all study alternatives. More detail on this assumption and potential future refinements is provided in the storm surge barrier sub-appendix. If further refinement for optimization or adaptation render changing of the closure criterion necessary; the performance of the RRFs would have to be re-evaluated.

2.7 Geometry

The geometric considerations are necessary to ensure the proper function of, and safe access to and across, the SBMs. The geometric considerations for the SBMs are listed below:

- Vehicle Access Ramp Slope (maximum): 10H:1V
- Vehicle Access Ramp Width –Two-Lane (minimum / desirable): 24 feet / 32 feet
- Levee Crest Width (minimum/ desirable): 10 feet / 15 feet
- Levee Front Slope (minimum/ desirable): 2H:1V / 3H:1V
- Levee Back Slope (minimum/ desirable): 2H:1V / 3H:1V

- Revetment Front Slope (minimum/ desirable): 2H:1V / 3H:1V

2.8 Stability Analysis for Gravity Structures

The stability analysis investigates the following:

1) Sliding: The structure moving horizontally.
2) Bearing: The structure sinks into the ground, caused by a lack of soil bearing capacity and/or an insufficient foundation design.
3) Resultant Location: The entire base must be in compression for the usual load condition to maintain full contact between the structure and the foundation. For extreme load conditions, the resultant is permitted to be anywhere within the base.
4) Settlement: Not analyzed at this time.
5) Seismic Stability: Not analyzed at this time.

Stability analysis shall be in accordance with USACE publications. The minimum factors of safety and resultant location limits are provided in the table below.

Table 2-4: Minimum Factors of Safety or Limits (EM-1110-2-2100)

Loading Condition Categories	Sliding, Factor of Safety	Bearing, Factor of Safety	Resultant Location, Limit
Usual	3.0	3.0	100% of Base in Compression
Unusual	2.6	2.3	75% of Base in Compression
Extreme	2.2	2.0	Resultant Within Base

In general, the stability analysis shall also consider scour, long-term erosion, piping, and seepage effects in the next stage, and it shall meet criteria set forth in FEMA's Guidance for Flood Risk Analysis and Mapping – Guidance Document 42 – Coastal Structures (FEMA, 2015). Seepage flow rate and gradient for piping stability were estimated through flow net analysis for a typical two-dimensional section. Scour and long-term erosion shall be investigated in the next phase of the project.

2.8.1 Pile Foundations

For axial loads in compression and tension, the ultimate capacity shall be determined in accordance with EM-1110-2-2906.

2.9 Design Load

2.9.1 Dead Loads

Structures shall be designed for material self-weight. The unit weights of materials frequently used as part of the preliminary design of SBMs are shown in Table 2-5.

Table 2-5: Material Unit Weights

Material Unit Weight	Pound/ft3
Steel	490
Concrete (normal weight)	150
Water (salt)	64
Riprap	132

2.9.2 Live Loads

The structures shall be designed for a uniform live load of 100 psf per Table 4-1 in ASCE 7-10.

Access roads shall be designed for a uniform live load of 250 psf in accordance with AASHTO design specifications.

2.9.3 Wind Loads

The structure shall be designed for a Category IV in accordance with ASCE 7-10. The design wind speed is 130 mph.

2.9.4 Seismic Loads

Seismic loads shall be determined per ASCE 7-10 and the New York City Seismic Code. This loading scenario was not assessed for this feasibility stage but will be considered during preconstruction, engineering, and design (PED).

2.9.5 Vessel Impact Loads

For SBMs that are directly adjacent to waterways, vessel impact loading will need to be considered. This loading scenario was not assessed for this feasibility stage but will be considered during PED.

2.9.6 Debris Impact Loads

For SBMs that are directly adjacent to waterways, debris impact loading will need to be considered. This loading scenario was not assessed for this feasibility stage but will be considered during PED.

2.9.7 Flood Loads

Unusual and extreme flood loads defined in EM 1110-2-2104 are described below:

Unusual:

Hydrostatic loads for the 0.2% AEP (500-year return period) design storm condition are based on the design 0.2% AEP still water level listed in the Section 2.6.5.

Wave loads shall be calculated using methodologies as described in the USACE CEM and consider using the 0.2% AEP (500-year return period) wave conditions defined in Section 2.6.6 in combination with hydrostatic loads for the 0.2% AEP (500-year return period) SWL.

Extreme:

Hydrostatic loads for the 0.13% AEP (750-year return period) design storm condition are based on the design 0.13% AEP still water level listed in the Section 2.6.5.

Wave loads shall be calculated using Goda as described in the USACE CEM and consider using the 0.13% AEP (750-year return period) wave conditions defined in Section 2.6.6 in combination with hydrostatic loads for the 0.13% AEP (750-year return period) SWL.

2.9.8 Temperature and Shrinkage

The temperature and shrinkage loading considered is a uniform change, 0°F to 120°F for steel or aluminum and 10°F to 80°F for concrete, in a moderate climate.

2.10 Load Combinations

Load combinations shall conform to *EM-1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures* and *EM-1110-2-2906 Design of Pile Foundations*.

2.11 Material Properties

All materials shall be new as described, or, if not stated, to be at least in accordance with the relevant American Society of Testing Materials (ASTM) Standards. The following material specifications were used as the minimum parameters for the preliminary design of the SBMs:

- Structural steel shall conform to ASTM A992 for wide flanges, A572 Grade 50 for other structural members.
- Steel sheet pilings, combi-wall systems and HP sections shall conform to ASTM A690 or ASTM A572 Grade 50; steel pipe piles shall conform to ASTM A252 Grade 3 (50 ksi).
- Steel reinforcement in concrete shall conform to ASTM A615, Grade 60.
- Reinforced concrete shall have a minimum 28-day compressive strength (f'c) of 5,000 psi, maximum water/cement ratio 0.40.

- Tremie concrete shall have a minimum 28-day strength of 7,000 psi.
- Lean concrete shall have a minimum 28-day compressive strength (f'c) of 3,000 psi.
- Minimum cover to reinforcement for concrete exposed to marine environment shall be 3 inches.
- Concrete shall be air entrained and conform to ACI 301.
- Structural steel members exposed to a marine environment shall be coated or galvanized. Steel foundations in the water, such as steel sheeting and steel piles shall be coated with coal tar epoxy and include 1/16 in. corrosion allowance in wall thickness (5/16 in. minimum).

3 Preliminary Design Development

3.1 Placement of SBMs, IFFs, and RRFs

The alignments of each of the NYNJHAT Study Alternatives was developed during the early plan formulation phase of the study; see also Section 1.3. Refinements and alterations to the SBM alignments were made over the course of the feasibility study. RRF alignments and IFF alignments were added to each study alternative, where applicable, during the feasibility study since those were not defined in the early plan formulation stage of the study. The locations for IFFs and the IFF alignments were based on the analysis of induced flooding for each of the study alternatives. An analysis of storm surge patterns for a select set of storms was evaluated with ADCIRC by U.S. Army Engineer Research and Development Center (ERDC). A detailed description of this analysis is provided in Annex B and can be summarized as follows. In locations where 1% AEP water levels are estimated to increase by more than half a foot, compared to the "without-project" condition, the area is marked for a potential need for induced flood mitigation. Through a desktop-level evaluation of each of these areas, it is assessed whether SBMs are already present within this location (in this instance, the SBM will mitigate for induced flood risk) or, if no SBMs are present, whether additional SBMs (in this instance referred to as IFFs) are needed to provide for flood risk reduction. The need for such measures depends on the evaluation of the inundated area, and generally any developed, non-natural, inundated area has been assigned an IFF alignment. Maps of the IFF alignments for each alternative are provided in Annex D.

A similar methodology was applied to establish the RRF alignments. Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary RRFs to manage the risk of more frequent flooding are proposed for developed, non-natural areas. The RRF alignments mitigate residual flood risk under the assumption that the SSB closure criterion is El. +7 ft NAVD88. The need for RRF alignments to provide for flood risk reduction was evaluated through a desktop-level evaluation of each of the coastal areas upstream of the storm surge barriers subject to inundation at the +7 ft NAVD88 flood level (see the blue shaded areas in Section 1.3 for the RRF coastlines of interest). Specifically, RRFs are only considered in the basins enclosed by the six large storm surge barrier complexes, as indicated in Table 3-1. The residual flood risk for the coastal areas upstream of the other storm surge barriers is mitigated by a lower closure elevation (i.e., more frequent operation of the SSB) or the flood risk is minimal for the elevation of +7 ft NAVD88 due to natural relief.

Table 3-1: Storm surge barriers per study alternative and whether the basin upstream of the storm surge barriers include RRFs

Name	Abbr.	Type	Alt. 2	Alt. 3A	Alt. 3B	Alt. 4	Alt. 5	RRFs in Basin
Outer Harbor	OH	SSB	YES					Yes
Throgs Neck	TN	SSB	YES	YES				Yes
Verrazzano Narrows	VN	SSB		YES				Yes
Arthur Kill	AK	SSB		YES	YES			Yes
Jamaica Bay	JB	SSB		YES	YES	YES		Yes
Kill van Kull	KVK	SSB			YES			Yes

Name	Abbr.	Type	Alt. 2	Alt. 3A	Alt. 3B	Alt. 4	Alt. 5	RRFs in Basin
Hackensack River	HR	SSB				YES		No
Newtown Creek	NC	SSB			YES	YES		No
Gowanus Canal	GC	SSB			YES	YES		No
Flushing Creek	FC	SSB			YES	YES		No
Sheepshead Bay	SB	SSB		YES	YES	YES		No
Gerritsen Creek	GRC	SSB		YES	YES	YES		No
Induced Flooding mitigation Features								
Eastchester Creek	EC	IFF SSB	YES	YES				No
Port Washington	PW	IFF SSB	YES	YES				No
Hempstead Harbor	HH	IFF SSB	YES	YES				No
Hammond Creek	HC	IFF SSB	YES	YES				No
Highlands	HL	IFF SSB		YES				No
Raritan River	RR	IFF SSB		YES				No

Generally, developed, non-natural, inundated areas have been assigned RRF alignments. Maps of the RRF alignments are provided in Annex D.

3.2 Methodology for Development of SBMs as part of NYNJHATS Alternatives

A limited series of reasonable and conceptually generic structural measures to provide flood risk reduction that can be used throughout the NYNJHAT Study Area were developed. The purpose of the study is to develop generalized SBMs that are comprehensive enough to be applicable and suitable for the entire study area yet not too detailed or site specific that they could only be applied at one location. The start point for the development of SBMs relied on three items: 1) The alignments of each of the NYNJHAT Study Alternatives (as developed during the early phases of the study, during plan formulation – see also Section 1.3); 2) a sub-set of structural measures from a list of coastal storm risk management measures from the NACCS report (USACE, 2015) – see Table 3-2, and 3); a list of High-Frequency Flood Risk Reduction Features (HFFRRF) included in the FINAL Integrated Hurricane Sandy General Reevaluation Report; and Environmental Impact Statement Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Appendix A1 (USACE, 2018a).

Table 3-2: Structural Measures for Coastal Storm Risk Management from NACCS

Structural Measures	Included within NYNJHAT Study as Shore Based Flood Risk Reduction Measure (SBM)	Note
Seawall + Revetment	Yes	
Groins	No	No to little flood risk reduction function
Detached Breakwater	No	No to little flood risk reduction function
Levee	Yes	
Floodwall	Yes	
Tide Gate	Yes	
Deployable Floodwall	Yes	
Road or Rail Raising	Yes	
Beach and Dune Restoration	Yes	
Storm Surge Barrier	No	Storm Surge Barrier is a flood risk reduction measure but not included within the category SBM

The selected set of structural measures from the table above (Seawall, Levee, Floodwall, Deployable Floodwall, Tide Gate, Road Raising and Beach and Dune Restoration) were then refined and expanded upon using the methodology described hereafter. The methodology is characterized as a desktop study where a high-level assessment and analysis is performed with limited data and which, in large part, relies on evaluation of aerial photography, site photos, readily available public data and professional engineering judgment. The general process combined both the evaluation of the applicability of SBMs for each alignment as well as the evaluation of the need for minor realignments to accommodate the SBMs and minimize conflict. The general methodology used for all the SBM reaches that are part of the NYNJHAT Study Alternatives can be described by the following 3 steps:

1. Assess existing shorelines and coastal edges and develop a general understanding of existing conditions, shoreline type, planned projects, land uses, spatial constraints, and elevation at the coastal edge;

2. Assess the potential for application of standard SBMs (those selected from Table 3-2) and assess potential conflicts with site integration:

    1. If the potential for conflicts during integration is deemed low or acceptable

        - Select most applicable SBM and assign it to a reach;

    2. If conflict for site integration is deemed high[5]:

        - Assess potential for re-alignment of the reach and assign the most applicable SBM (note that a full alternate alignment evaluation was not included, and only small/minor changes were made where deemed feasible), OR

        - Identify a new SBM typology which would potentially result in lower degree of conflict; and

3. If multiple locations have been identified where a SBM is different from the typical list (those selected from Table 3-2) would be preferable, then develop a preliminary design for said SBM.

Following the methodology above, and with the objective of developing generalized SBMs that are comprehensive enough to be applicable and suitable for the entire study are, yet not too detailed or site specific that they could only be applied at one location, the list of structural SBMs from Table 3-2 was expanded. The expanded list of SBMs is provided below. For completeness, it is once more reiterated that measures used for IFFs are SBMs; the IFF nomenclature only highlights the fact that such measures address the induced flooding risk

<u>SBMs for the NYNJHAT Study</u>:

- Floodwalls
    - Medium Floodwall (reveal height of 6.5 ft)
    - Large Floodwall (reveal height of 12 ft)
    - Extra Large Floodwall (reveal height of 16.5ft)
- Levees
    - Medium Levee (reveal height of 7 ft)
    - Large Levee (reveal height of 12 ft)
- Elevated Promenade
- Floodwall with Park Integration
- Seawall
- Reinforced Dune
    - Reinforced Dune – Natural Dune Cover for natural shoreline application, and
    - Reinforced Dune – Partial Dune Cover for urban application

[5] A record of relative qualifiers is kept offline for each reach within a geographic information system database

- Deployable Flood Barriers
    - Flip-up Barrier
    - Pedestrian, Vehicular and Railroad Gates
- Tide Gate

For RRFs, the structural measures were based on an earlier completed feasibility study within the study region, *FINAL Integrated Hurricane Sandy General Reevaluation Report and Environmental Impact Statement Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Appendix A1* (USACE, 2018a). In the 2018 report, HFFRRFs for the Jamaica Bay area with a reveal height (the height between top of wall and ground level) ranging from 3 ft to 8.5 ft were developed for areas at risk of high frequency flooding. Those HFFRRFs in the Jamaica Bay Feasibility Study provide the same function as the RRFs under the NYNJHAT Study. Since the RRFs have similar reveal height and are applied in the same region, the HFFRRFs designs were adopted and used as the starting point for the design of the RRFs under the NYNJHAT study. The RRFs are listed below.

<u>RRFs for the NYNJHAT Study</u>:

- Floodwalls
    - Low Floodwall (reveal height of 3 ft)
    - Standard Floodwall (reveal height of 5 ft)
    - High Floodwall (reveal height of 8 ft)
- Berm
    - Low Berm
    - Medium Berm
    - High Berm
    - Hybrid Berm
- Bulkhead
    - Shallow Bulkhead
    - Deep Bulkhead
- Revetment with Floodwall
- Tide Gate
- Deployable Flood Barriers

    - Pedestrian and Vehicular Gates

- Road Ramp
- Road Raising

The following section first provides a brief explanation of the evaluation of existing shoreline conditions and the compatibility and selection of SBMs under this study (step 1 and 2 of the methodology, above). Thereafter the development of the preliminary designs of the SBMs and RRFs is presented.

3.3 Existing Shoreline Considerations

With the use of publicly available data and satellite images, existing shoreline features for all the study areas were assessed and classified into the categories shown in Table 3-3. Based on the existing features that prevail throughout the study area, and the list of prototypical SBMs, the general applicability of the SBMs by existing shoreline feature type was determined. It should be reiterated that no site-specific topographic survey, bathymetric survey, condition survey, and geotechnical analysis have been completed. Instead, in accordance with USACE's SMART planning principles, the development of the feasibility level SBMs was based on qualitative data and desktop-level analysis, which resulted in broad generalizations of existing conditions. The implications of such assumptions along with recommendations for further data collection and refined analysis to support the design are described in Section 5.

Table 3-3: Existing Shoreline Features and General Applicability of SBMs

Existing Shoreline Type \ SBMs	Floodwall	Levee/ Berm	Elevated Promenade	Floodwall with Park Integration	Bulkhead	Seawall/ Revetment with Floodwall	Reinforced Dune – Natural Dune Cover, Partial Dune Cover	Deployable Flood Barrier - Flip-up Barrier	Deployable Flood Barrier – Pedestrian, Vehicular, Railroad Gates	Tide Gate	Road Ramp	Road Raising
Natural Shoreline	√	√										
Revetment			√			√						
Parks/ Uplands		√		√								
Street End/ Crossings	√								√		√	√
Urban Waterfront Development	√		√		√			√				
Industrial Waterfront Development	√				√	√						
Promenade	√		√					√				
Bulkhead					√							
Beach							√					
Streams, Creeks, Waterways or Canals										√		

3.4 Design Development of SBMs

Based on the design criteria described in section 2 and available data, preliminary designs commensurate with a feasibility study level were developed for the SBMs. As noted earlier, the SBM designs are also used for the locations where IFFs are proposed since both SBMs and IFFs mitigate for risk associated with the 1% AEP flood event. The description and limitations of each SBM is discussed below.

3.4.1 SBM – Floodwall

Floodwall systems are independent, single purpose structures that aim to provide flood risk reduction. A floodwall is typically a reinforced concrete structure supported on steel H-piles, which can incorporate a steel sheet pile cut-off wall as a seepage control measure. Figure 3-1 shows a section of a floodwall that has been constructed as part of the Hurricane and Storm Damage Risk Reduction System Design Guidelines (HSDRRS) (USACE, 2016).

Based on the range of existing site elevations and required design elevations, a total of three types of prototypical floodwall were developed for NYNJHAT Study. Three of the floodwalls were developed as regular SBMs and were labeled as “medium”, “large”, and “extra-large”.

All three types of floodwall are composed of an inverted T-shape reinforced concrete structure with a base of 4-foot thick, battered H-piles and a vertical steel sheet pile cut-off wall. For the medium, large, and extra-large floodwalls, the existing ground elevations were assumed to be El. 12’, El. 9’, and El. 6’; the top of the wall elevations were set at El. 18.5’, El. 21’, and El. 22.5’. Typical cross-sections for medium, large and extra-large floodwall are shown in Figure 3-2, Figure 3-3 and Figure 3-4, respectively. Pile design depends on design loads and soil parameters. For this study, soil characteristics as described in Section 2.6.2 were used.

Due to the relatively small footprint, a floodwall is deemed suitable for flood-prone urban waterfront areas, both directly at the shoreline and farther inland, where there are no existing structures and viewshed impacts are of lesser concern. It should be noted that flood-prone waterfront areas are likely to have poor soil conditions and require excavation and backfilling prior to construction.

Figure 3-1: Floodwall Construction in New Orleans (USACE, New Orleans District)

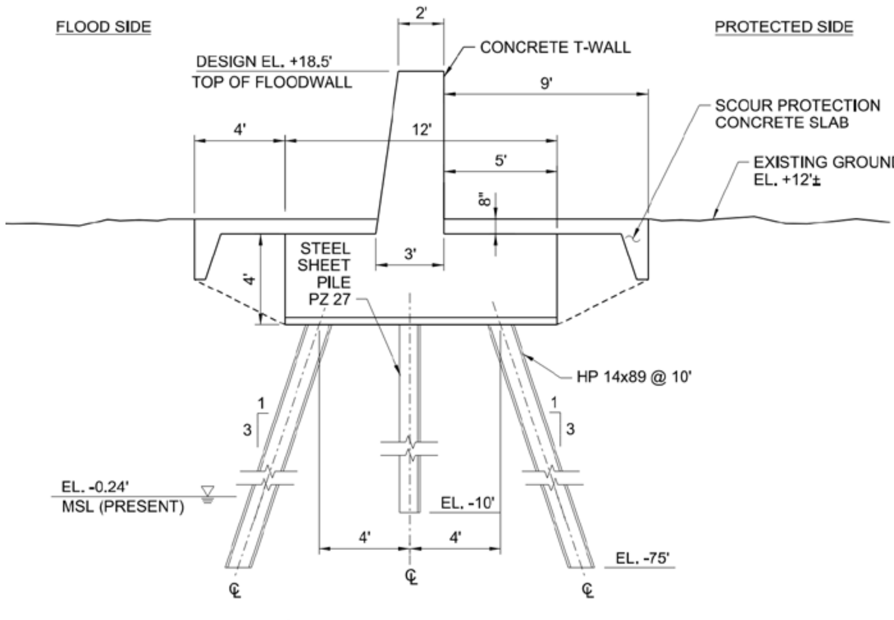

Figure 3-2: SBM Medium Floodwall Cross-Section

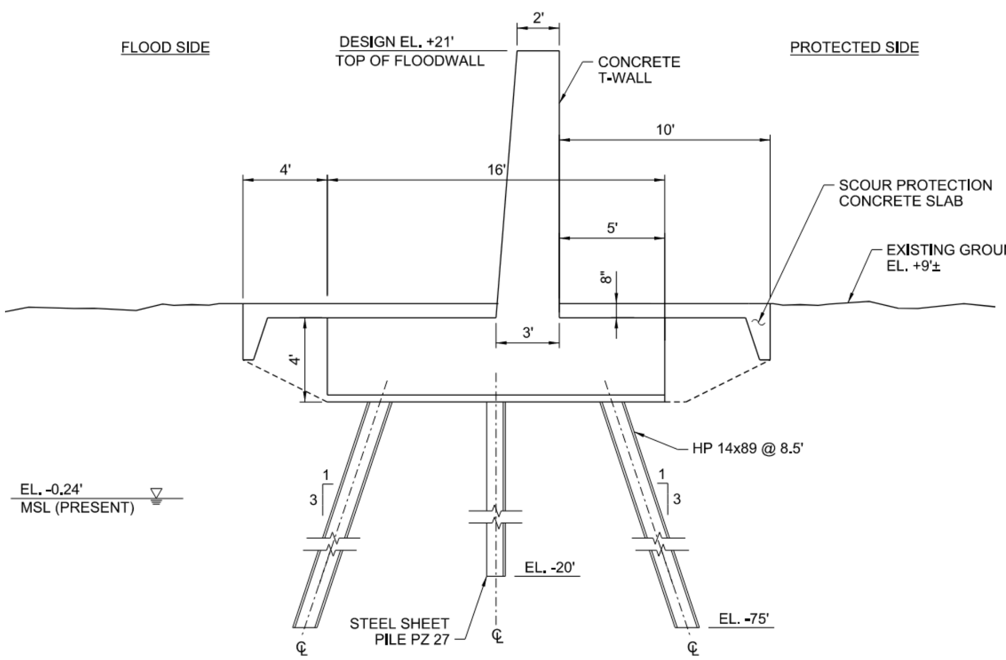

Figure 3-3: SBM Large Floodwall Cross-Section

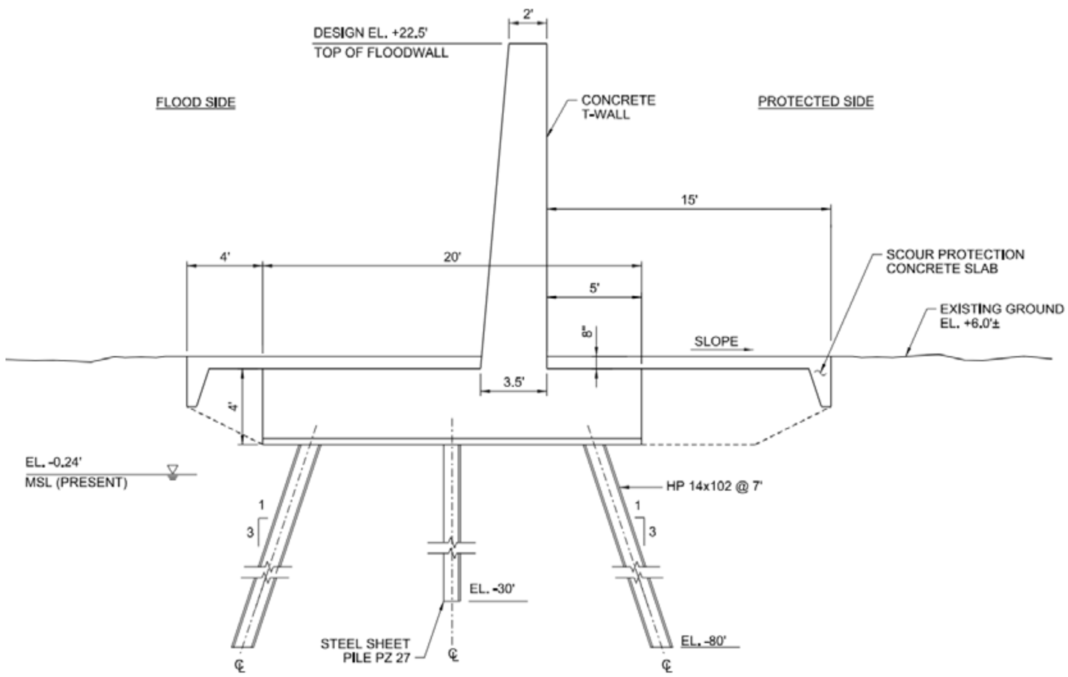

Figure 3-4: SBM Extra-Large Floodwall Cross-Section

3.4.2 SBM – Levee

Whereas floodwalls are made of materials such as reinforced concrete and steel, levees are made of compacted soil with grassy vegetation on top. Levees are commonly used along rivers, coastlines, and bodies of water to prevent inland flooding in the case of rising water levels.

Levees are typically constructed by placing engineering fill on a cleared and leveled surface; soil is compacted in layers into a large earthen structure that is wide at the base and tapers toward the top. The interior of the levee is a core composed of impervious material, usually a firm clay, to form a watertight barrier to prevent or minimize seepage, either through or beneath the section. Side slopes are composed of sand for stability and protection of the core layers. Grass or some other types of non-woody vegetation are commonly planted on the levee to add stability and protection from erosion. The vegetation on the levee increases its aesthetic appeal. A photograph showing a levee after completion can be found in Figure 3-5.

Levees on poor soil are subject to instability, uncontrolled drainage flows, and settling, and therefore require deeper excavation prior to construction. For this study, it was assumed the levee is founded on soil of medium quality. As discussed in Section 2.6.2, no site-specific geotechnical analysis was completed. For the prototypical design for the levee, 6 feet of material would be excavated from the ground for seepage control, and a side slope of 1 vertical on 3 horizontal was used to minimize erosion and scour potential. The medium levee has a height of 7 feet and the large levee has a height of 13 feet. To minimize seepage concerns, facilitate maintenance, and allow for ease of construction, a crest width of 10 feet and 15 feet were used for the medium and large levee design, respectively.

Due to the levee width, required setbacks and space needed for smooth grade changes, relatively large tracts of real estate are typically required. For this reason, levees are best used as flood risk reduction measures along natural shoreline, or parallel to the course of streams, and set away some distance from the developed areas. Figure 3-6 and Figure 3-7 show the cross-section of a typical medium levee and large levee, respectively.

Figure 3-5: Levee in New Orleans (USACE, New Orleans District)

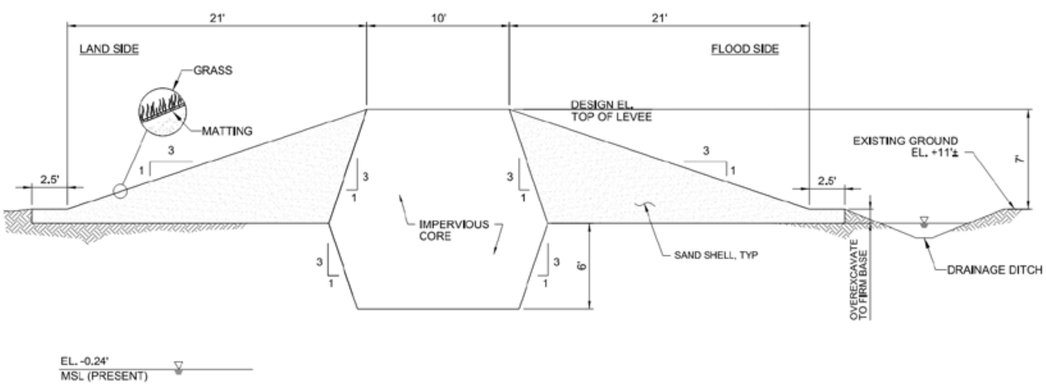

Figure 3-6: SBM Medium Levee Cross-Section

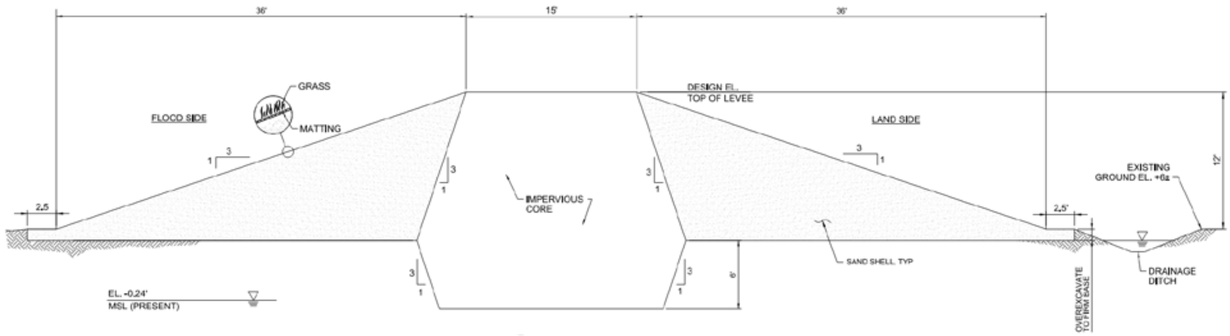

Figure 3-7: SBM Large Levee Cross-Section

3.4.3 SBM – Elevated Promenade

The prototypical elevated promenade concept seeks to preserve a waterfront space and view that is available to the public but yet still able to provide flood risk reduction. The elevated promenade consists of a 27.47-foot diameter steel flat sheet cofferdam with sand backfill inside, and a reinforced concrete cap of 18-inch thick. The existing ground and existing mudline were assumed to be El. 9' and El. -5', respectively.

The elevated promenade was assumed to be constructed along the shoreline to replace an existing promenade. It should be noted that temporary structures to shore up the existing promenade are likely required during demolition and construction. Detailed design would be completed during later stages of the study when site specific parameters are available.

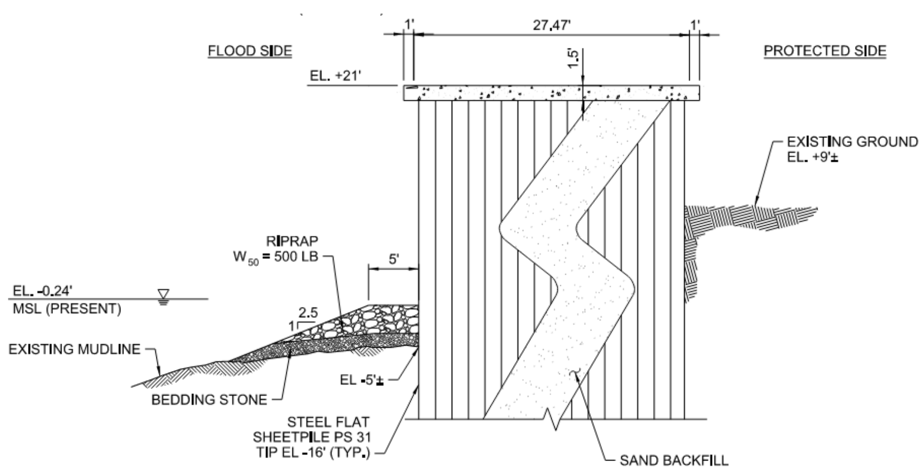

Figure 3-8: SBM Elevated Promenade Cross-Section

3.4.4 SBM – Floodwall with Park Integration

A variation of the floodwall measures described in Section 3.4.1 was developed to provide flood risk reduction to urban areas behind the floodwall while also providing or maintaining a public amenity and open space along the waterfront, whilst at the same time reduce the incoming wave height and wave loading on the floodwall structure.

The floodwall with park integration SBM is composed of a H-pile supported T-shape reinforced concrete floodwall with a vertical sheet pile cut-off wall (see Section 3.4.1), and an elevated park on a berm. The existing ground elevations is assumed to be at +10 feet; the top of the wall elevation was set at +23 feet. The elevated park is located on the flood side of the floodwall and is supported on a berm made of compacted soil and vegetation. Typical cross-section for the floodwall with park integration is shown in Figure 3-9.

The measure integrates well with existing urban waterfront areas; however, the park space requires a relatively large footprint. It should be noted that the existing promenade was assumed to have a soil retaining structure that would require some reinforcement. Detailed design would be completed during later stages of the study when site specific parameters are available.

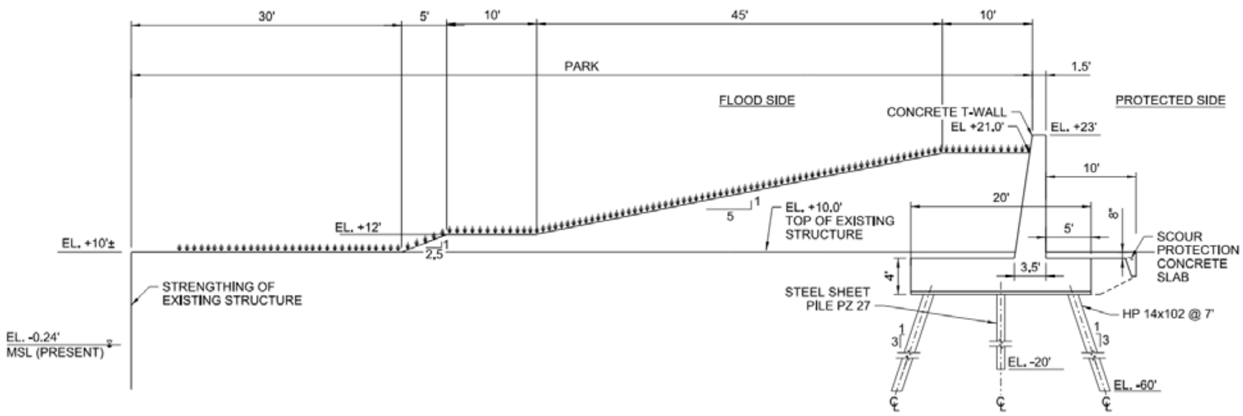

Figure 3-9: SBM Floodwall with Park Integration Cross-Section

3.4.5 SBM – Seawall

The seawall is a composite structure and is comprised of a rubble mound structure and an H-pile supported T-shape reinforced concrete floodwall with a vertical sheet pile cut-off wall. Figure 3-10 shows an example of a rubble mound structure in the Bronx, New York.

Figure 3-10: Rubble Mound Structure in Bronx, New York (M&N, 2017)

It should be noted that a rubble mound structure[6] is effective in dissipating wave energy but cannot prevent coastal flooding since it is porous. The impervious concrete floodwall would be installed in combination with the rubble mound structure to prevent flooding and reduce wave run-up. The prototypical design for the seawall is composed of a rubble mound structure on the seaward side and a pile supported concrete floodwall on the landward side. For this study, it was assumed that a rubble mound with two layers of 2.8-foot diameter armor stone and two layers of 1.3-foot diameter underlayer stone with a slope of 2 (Horizontal):1(Vertical) would provide sufficient stability. The underlayer would be on top of a geotextile; the geotextile would protect the underlaying base material or soil from erosion by waves and currents. The toe has a width of 12.2 feet. The floodwall has an inverted T-shape reinforcement concrete structure with a base of 4.5-foot thick, battered H-piles and vertical steel sheet pile cut-off wall. The top of the floodwall is at El. 27’ and the design existing ground elevation is at El. 7’.

One of the more important variables of the rubble mound design is the seaward side slope which, together with the crest height, is generally dictated by soil conditions and construction methods. For the purposes of this study, it was assumed that the rubble mound was founded on soils that are of moderate quality which is common in the study area per Section 2.6.2 and therefore would not require foundation/ground improvements. Bottom elevation of the rubble mound toe was assumed to be at Elevation -8’. Actual elevations will vary across the study area, but for feasibility-level

[6] Rubble mound structures can be symmetrical or asymmetrical. They are typically made of erosion resistant material, such as stone or concrete, to protect the shoreline against wave action. Rubble mound is typically composed of an armor layer, filter layer(s), and toe protection. The armor layer is designed to dissipate wave energy; as a result, the core can be protected from direct wave attack. The filter layer supports the armor, and it allows passage of water while retaining the underlying soil. The toe is to provide stability against undermining at the bottom of the structure.

analysis, it was considered a reasonable elevation representative of the conditions of application within the study area. A typical cross-section for the seawall is shown in Figure 3-11. Finally, rubble mound structures, especially the ones with natural stone armor, integrate well with the natural shoreline. The natural look of the armor rock has a relatively higher aesthetic appeal.

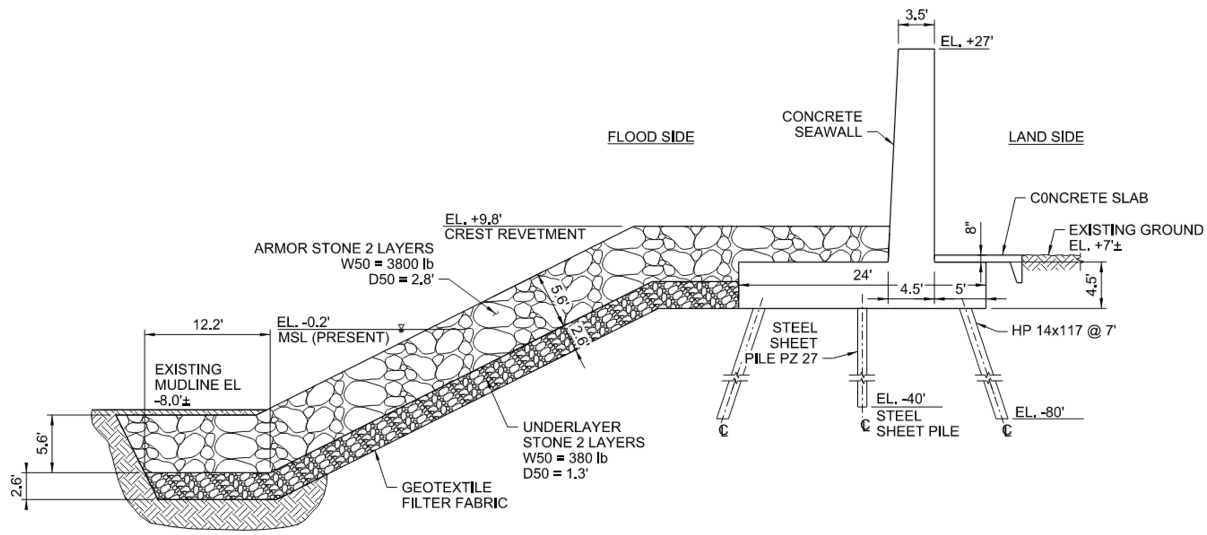

Figure 3-11: SBM Seawall Cross-Section

3.4.6 SBM – Reinforced Dune

A horizontal reinforced dune similar to the design developed for the *Atlantic Ocean Shorefront Reach of the Rockaway Peninsula* (USACE, 2018a) is included within the NYNJHAT Study as a SBM to provide a reduction in flood risk. Two measures were developed: namely, the reinforced dune (natural dune cover) as shown in Figure 3-13, and the reinforced dune (partial dune cover) as shown in Figure 3-12. The partial dune cover variation to this SBM is proposed to be applied in more developed beach areas where spatial constraints are more apparent. The double retaining wall limits the extent of the splash apron and thereby the footprint of the measure. The "natural dune cover" of this SBM has structural core but is completely covered in sand and has a larger footprint.

Both reinforced dune configurations are based on the same general horizontal composite seawall design developed for the *Atlantic Ocean Shorefront Reach of the Rockaway Peninsula* (USACE, 2018a) because the SBM alignments where this measure applies overlaps to a great extent with the shorefront reach of the rockaway peninsula. For the reinforced dune, the design SWL, which is slightly lower than reported below, is noted in *Atlantic Ocean Shorefront Reach of the Rockaway Peninsula* Table 4-2 (USACE, 2018a), and the design wave characteristics are noted in Table 4-4 of the same document (USACE, 2018a).

For the reinforced dune, an overtopping rate of 1 cfs per foot or 93 l/s/m was adopted (analogous with the design of the reinforced dune at the Rockaway Peninsula, NY). The structure consists of a 1-layer rubble mound structure with an impermeable core, a 1V:2H slope, and a steel sheet pile with a concrete cap that functions as a flood risk reduction barrier. A concrete cap top elevation of +19.5 feet was provided; a dune crest elevation of +21.5 feet with a crest width of 25 feet was used. The existing grade behind the sheet-pile retaining wall was assumed to be at an elevation of +7.5'. For reinforced dune with natural dune cover, a layer of sand was on top of the rubble mound and concrete cap to enhance visual aesthetic and integration to the existing environment. A typical cross-section for the overall reinforced dune with partial dune cover is shown in Figure 3-14.

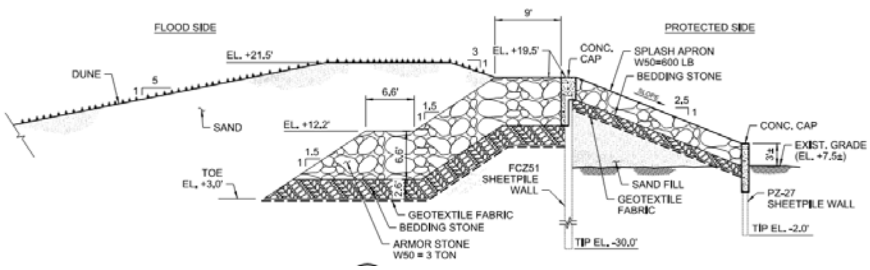

Figure 3-12: SBM Reinforced Dune with Partial Dune Cover Cross-Section

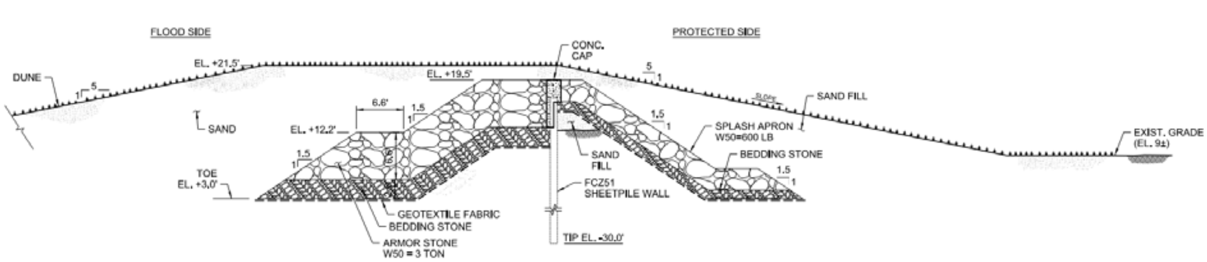

Figure 3-13: SBM Reinforced Dune with Natural Dune Cover Cross-Section

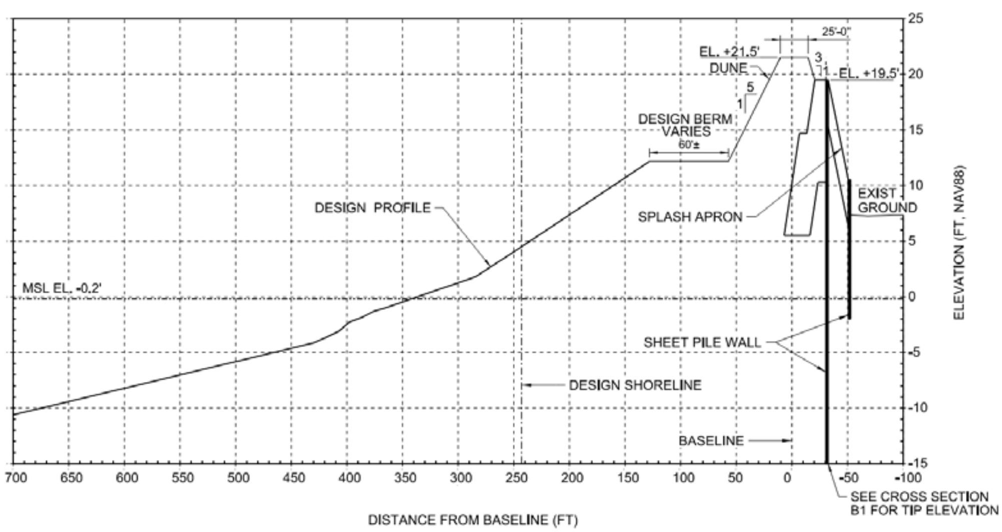

Figure 3-14: SBM Typical Overall Cross-Section for Reinforced Dune with Partial Dune Cover

3.4.7 SBM – Flip-up Barrier

At certain locations where SBMs are considered as part of the NYNJHAT Study alternatives, the need to preserve viewsheds and maintain level and unimpeded access to the waterfront is essential. For those locations, a deployable flood barrier, i.e., the flip-up barrier, was considered and included as an SBM under the NYNJHAT Study. The flip-up barrier is under consideration in the Lower Manhattan Coastal Resiliency (LMCR) study (LMCR, 2018).

The flip-up barrier is a passive deployable flood barrier. The passive deployment mechanism allows deployment of the flip-up barrier without any involvement from operation personnel and is operated by physics (i.e., water pressure) and activated when the design conditions are met (i.e., at the onset of submergence of the base). Passive systems allow for operational flexibility and will ensure the flip-up barrier be deployed when needed to provide flood risk reduction. For the NYNJHAT Study, a flip-up barrier similar to the design developed for the LMCR study was considered. The LMCR flip-up barrier is designed to include a dual operating mechanism, i.e., it can be manually operated, but by default relies on its standard passive deployment mechanism. Manually operated barriers require operation personnel to physically go to the location of the barrier and close it during storm conditions. The barrier would then be locked into place to prevent tampering with. After deployment, access to the flood side of the alignment would be impeded.

A schematic view of the flip-up barrier is shown in Figure 3-15. The flip-up barrier for the NYNJHAT Study includes a barrier with a height of 16.5 feet. The advantage of a flip-up barrier is a small structural footprint with no to little viewshed impacts when the barrier is not deployed. Although most of the structure is housed underground when not deployed, public amenities cannot be permanently installed on top of the flip-up barrier. Nevertheless, the flip-up barrier will allow optimal waterfront access for public enjoyment.

The flip-up barrier was assumed to be supported on piles. Pile design depends on design loads and soil parameters. Since flood-prone waterfront areas are likely to have poor soil conditions, excavation and backfilling prior to construction may be required. Detailed design would be completed during PED when site specific parameters are available.

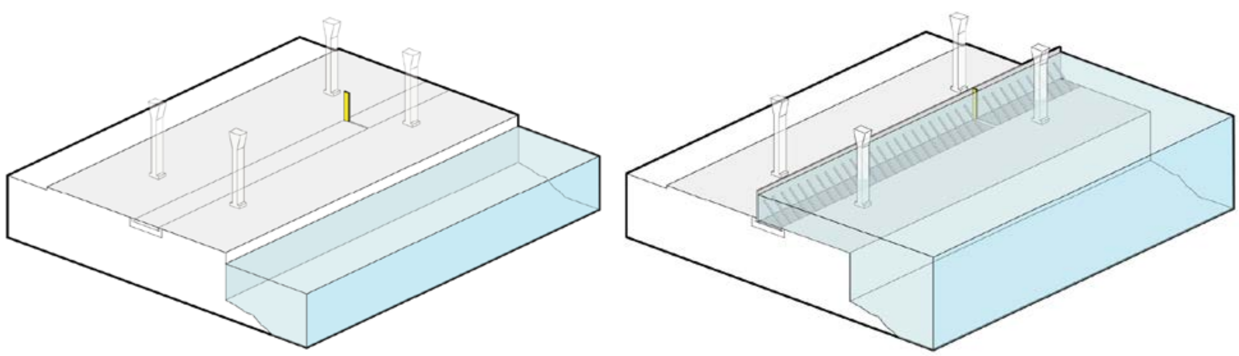

Figure 3-15: Schematic View of a Flip-up Barrier from LMCR

3.4.8 SBM – Pedestrian, Vehicular and Railroad Gates

Pedestrian, vehicular and railroad gates are deployable flood barriers added to a line of coastal storm damage risk reduction, across a road, driveway, or railroad crossing, which allows for unimpeded access across the alignment during normal day-to-day conditions. Deployable floodgates can be either manually or automatically operated; however, the prototypical deployable floodgate developed for this study is designed to be manually operated to be consistent with the latest local practices for such gates. Manually operated gates require operation personnel to physically go to the location of the gate and close it during storm conditions. The gate will then be locked into place to prevent tampering with and access to the flood side of the line of protection.

Both swing gates and roller gates were considered initially, the choice of gate type depends on the orientation and space available. In general, a roller gate can slide into place along a track (as illustrated in Figure 3-16 and Figure 3-17) and a swing gate is supported on one side by top and bottom hinges attached to a support structure (Figure 3-18). The cross-section of a typical 30-foot-wide swing gate is shown in Figure 3-19.

Both gate types have the advantage of being simple where relatively simple equipment is required. However, swing gates will require a relatively large right-of-way area for operating while roller gates will require a level track surface.

The gates were assumed to be 12 feet high and were supported on piles. Pile design depends on design loads and soil parameters. Since flood-prone waterfront areas are likely to have poor soil conditions, excavation and backfilling prior to construction may be required. Generic gate widths of 15 feet, 30 feet, and 60 feet were proposed for the pedestrian, vehicular and railroad gates, respectively.

At this stage of the study no preferred floodgate type has been selected and only an inventory of total number of gates will be completed. Floodgate type evaluation, gate size requirement and associated detailed design would be completed during the next phases of the study when site specific parameters are available.

Figure 3-16: Roller Gate (ETL-1110-2-2105)

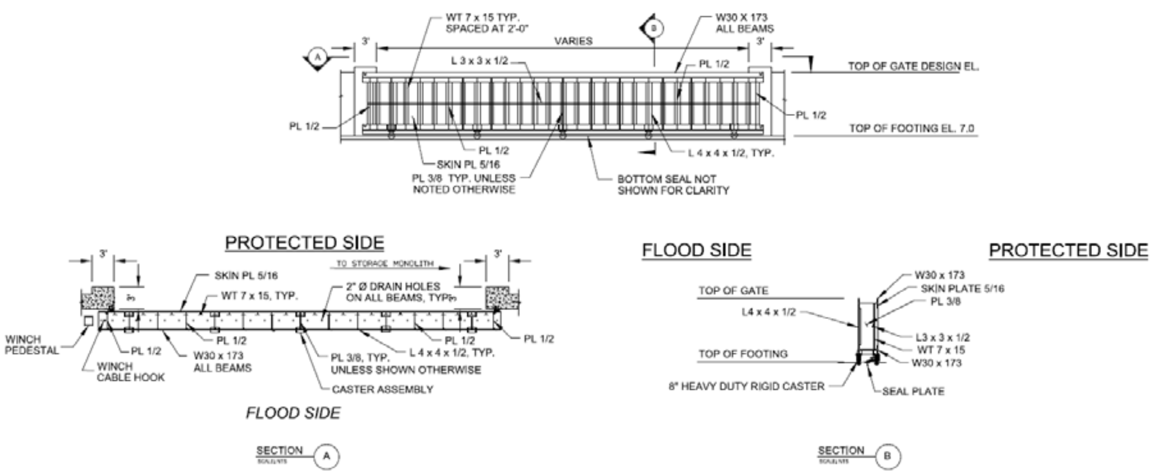

Figure 3-17: Roller Gate Cross-Section (USACE, 2016)

Figure 3-18: Single-leaf Swing Gate in New Orleans at a Railroad Crossing (M&N)

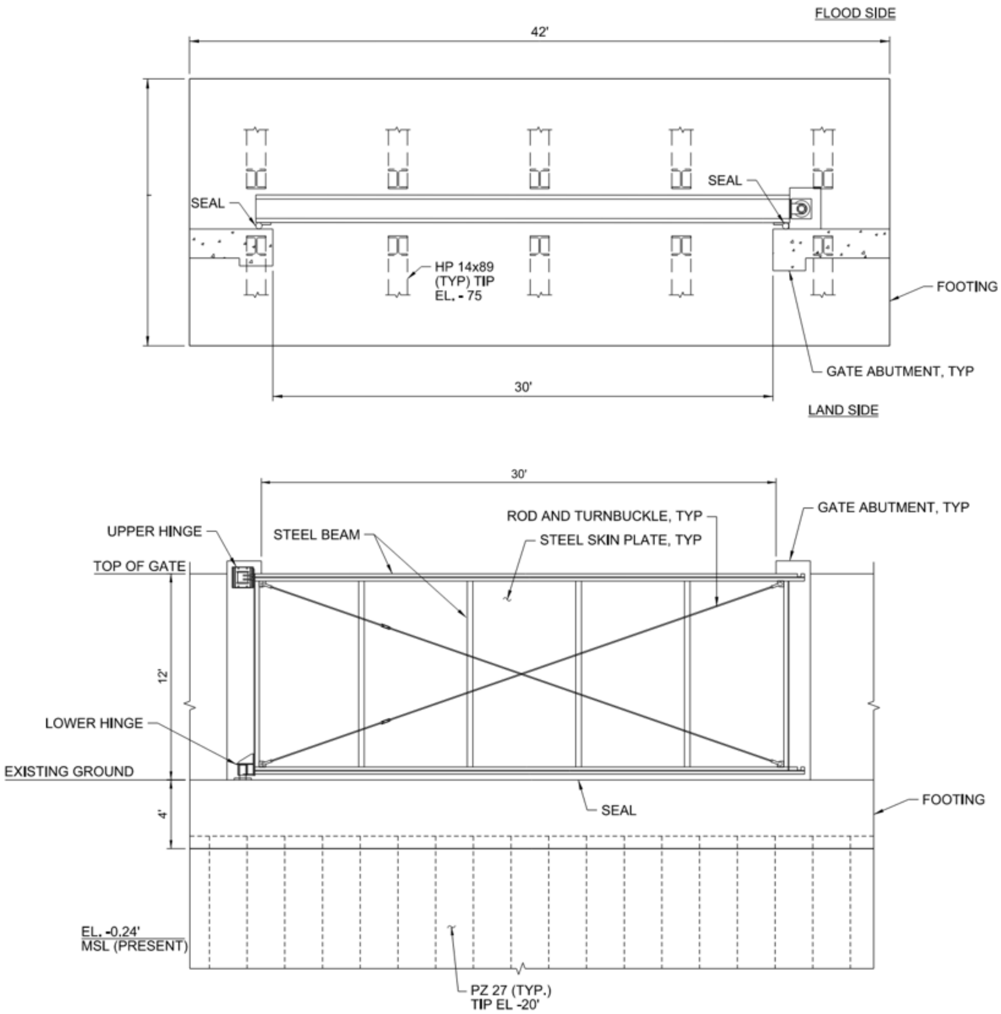

Figure 3-19: SBM Swing Gate Cross-Section

3.4.9 SBM – Tide Gate

Tide gates are coastal storm flood risk reduction measures that stay open under normal conditions to let tidal flow pass but are closed when water levels are expected to exceed a predetermined level. Tide gates do not allow for navigation or passage of vessels or small boats. A tide gate is typically a reinforced concrete superstructure supported on steel pipe piles, with a steel sheet pile cut-off wall as a seepage control measure. The tide gate design under NYNJHAT Study has a sill elevation of -4 feet and a top of wall elevation of +21 feet. The prototypical tide gate developed for this study is designed to include an electric winch and to be manually operated remotely. Figure 3-20 shows the cross-section of the tide gate.

The tide gates are assumed to be supported on piles. Pile design depends on design loads and soil parameters. Since flood-prone waterfront areas are likely to have poor soil conditions, excavation and backfilling prior to construction may be required. Tide gate type evaluation and associated detailed design would be completed during the next phases of the study when site-specific parameters are available.

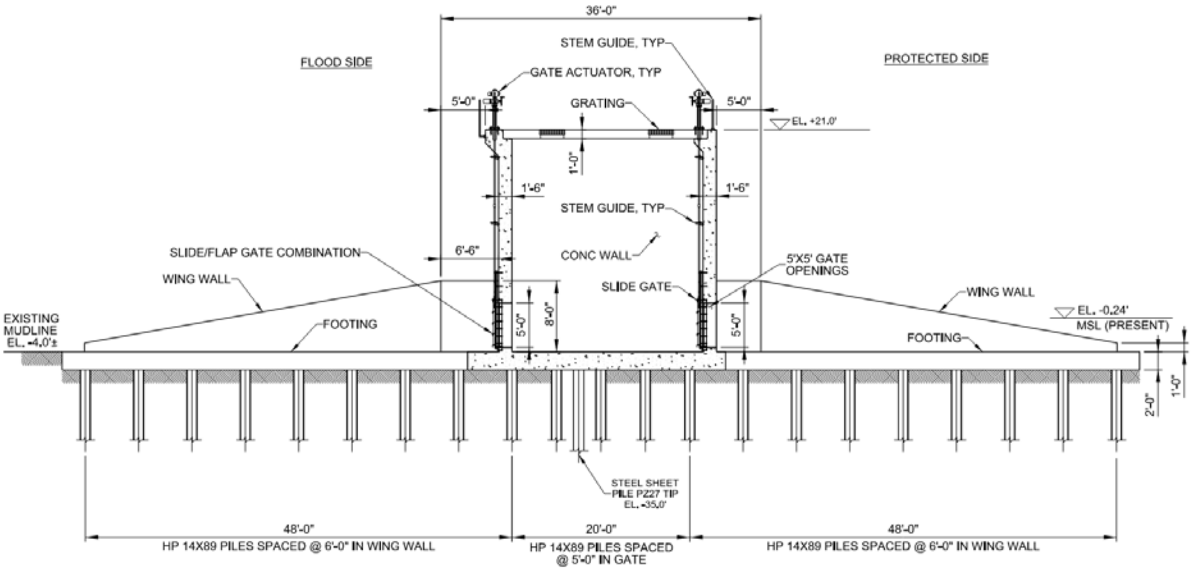

Figure 3-20: SBM Tide Gate Cross-Section

3.4.10 SBM – Road Ramp

Road ramps do not provide flood risk reduction but are a means of allowing vehicular access across the flood risk reduction alignment. For the NYNJHAT Study, road ramps were designed to be used in conjunction with the large levees and are placed in locations where levees cross existing roadways with few space constraints. , The road ramps consist of two traffic lanes developed to allow for safe vehicular crossing over a large levee section.

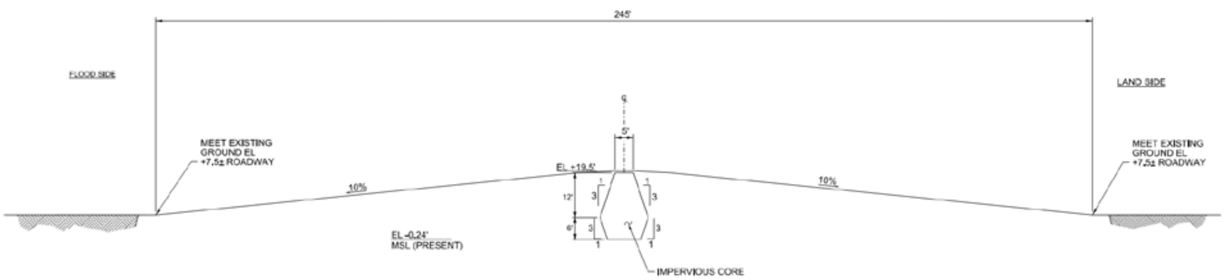

Figure 3-21: SBM Road Ramp Cross-Section

3.5 Design Development of RRFs

RRFs are measures that mitigate residual flood risk assuming a storm surge barrier closure criterion of +7 ft NAVD88 and have a crest elevation of 10 ft NAVD88 (see section 2.6.7). As discussed in Section 3.1, due to the similarity in application and design criteria, the RRFs were directly adopted from *FINAL Integrated Hurricane Sandy General Reevaluation Report and Environmental Impact Statement Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, Appendix A1* (USACE, 2018a).

3.5.1 RRF – Floodwall

A general description of the floodwall can be found in Section 3.4.1. Floodwalls developed as RFFs are similar to those developed as SBMs with the exception that the reveal heights for RRFs are typically much less than those of the SBMs.

Based on the range of existing site elevations and required design elevations, a total of three types of prototypical RRF floodwalls were developed for NYNJHAT Study. The RRF floodwalls developed were labeled as “low”, “standard”, and “high”, with a design top of wall elevation of 10 feet.

For the low floodwall design, the approximate existing ground elevation was assumed to be at El. 7 feet which is deemed appropriate for the typical site conditions. The L-shape reinforcement concrete structure terminates at El. 10 feet and is supported on the battered H-piles with the vertical steel sheet piles used as seepage control measure. A typical cross-section for the low floodwall is shown in Figure 3-22.

For the standard and high floodwalls, the approximate existing ground elevations were assumed to be El. 5 feet and El. 2 feet, respectively. The reinforced concrete structure is shaped like an inverted “T” and is supported on pairs of vertical H-piles. Typical cross-sections for the standard and high floodwall are shown in Figure 3-23 and Figure 3-24, respectively. Pile design depends on design loads and soil parameters. For this study, soil characteristics as described in Section 3 were used.

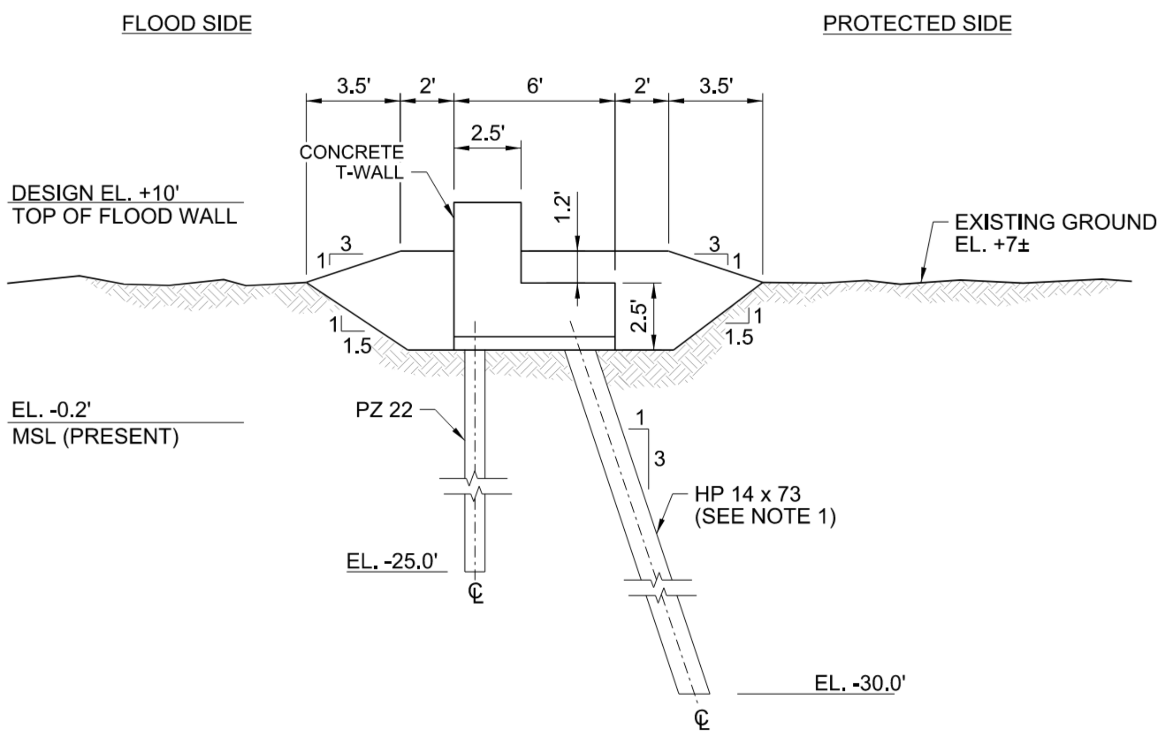

Figure 3-22: RRF Low Floodwall Cross-Section

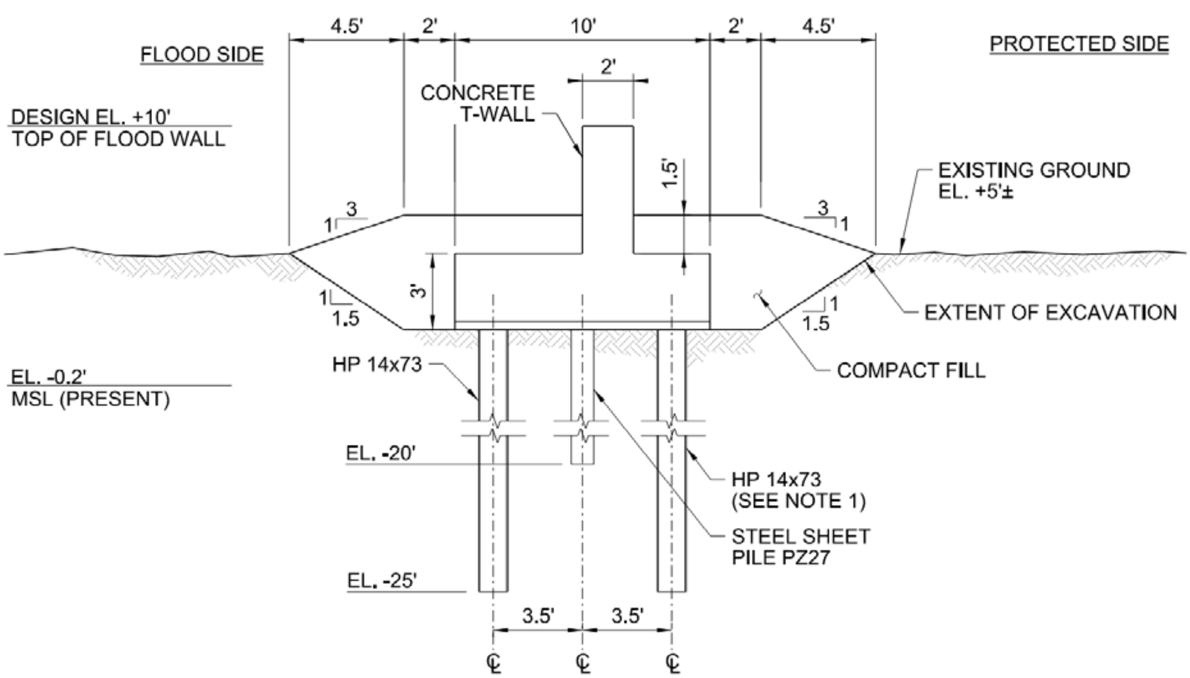

Figure 3-23: RRF Standard Floodwall Cross-Section

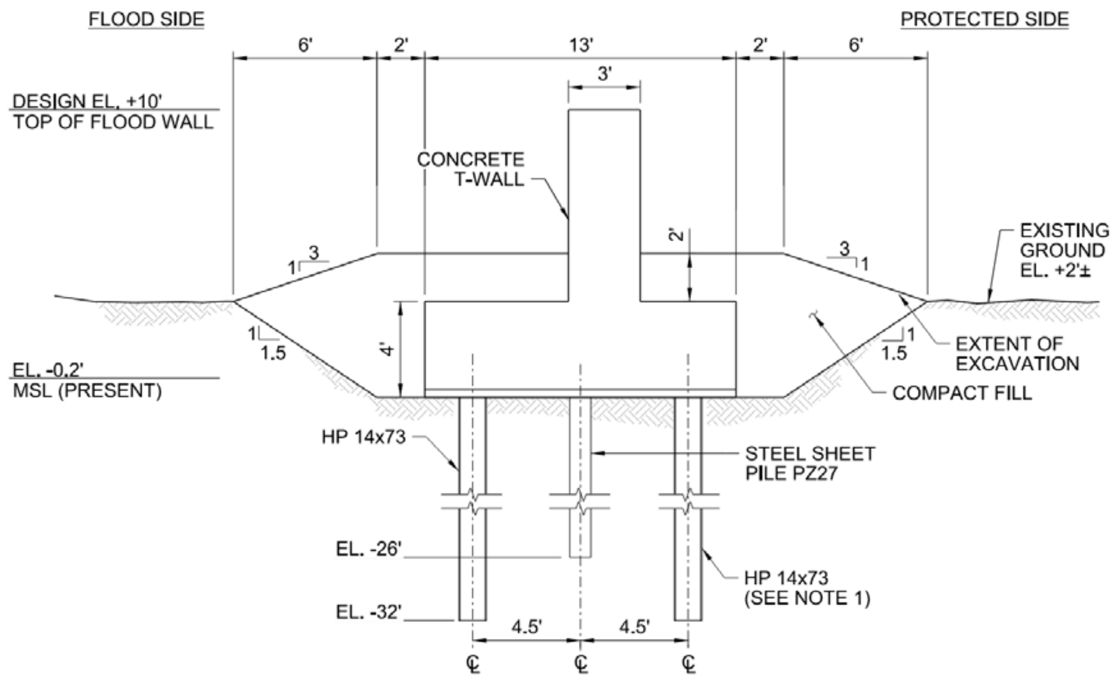

Figure 3-24: RRF High Floodwall Cross-Section

3.5.2 RRF – Berm

Berms developed as RRFs are smaller versions of the levees developed as SBMs. Berms are man-made earthen structures that have a wide base and a tapered crest at the design elevation of 10 feet. The general description for the levees, provided in Section 3.4.2, is applicable to berms.

Berms on poor soil are subject to instability and settling, and therefore require deeper excavation prior to construction. For this study, it was assumed the berm is founded on soil of medium quality. As discussed in Section 2.6.2, no site-specific geotechnical analysis was completed. For the prototypical design for the low berm, 5 feet of soft-consistency material would be excavated from the ground elevation of El. +7 feet. Similarly, for the medium and high berm, material would be excavated from the existing ground elevation of El. +5 feet and El. +1.5 feet, respectively.

To minimize seepage concerns, facilitate maintenance, and allow for ease of construction, a crest width of 5 feet and 7 feet was used for the low and medium berm design, respectively. Since the high berm also has to meet access requirements and future emergency needs, a 10-foot crest width was used in the design of the high berm. A side slope of 1 vertical on 2.5 horizontal was used for both the low, medium and high berm to minimize erosion and scour potential and provide sufficient stability.

Due to the berm width and required setbacks, relatively large tracts of real estate are usually required. For this reason, berms are best suited along natural shoreline or parallel to the course of streams and basins and set away some distance from the developed areas. To add stability and provide erosion protection, it is common to plant grass or non-woody vegetation on the berm. The vegetation allows for a natural aesthetic integration with the surrounding environment. Figure 3-25, Figure 3-26, and Figure 3-27 show the typical low berm, medium berm, and high berm, respectively.

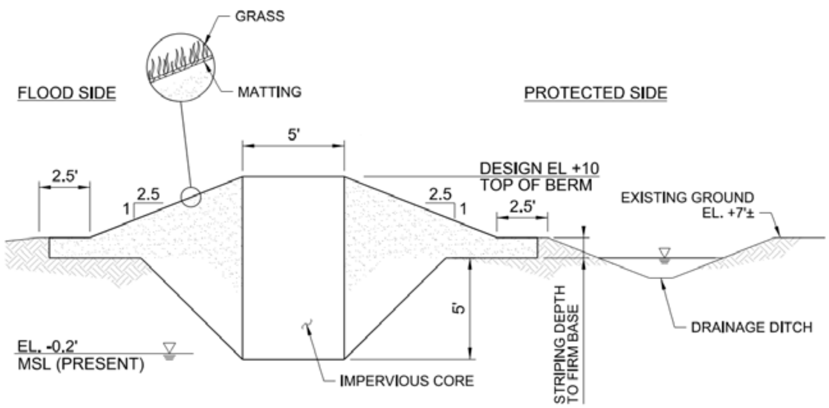

Figure 3-25: RRF Low Berm Cross-Section

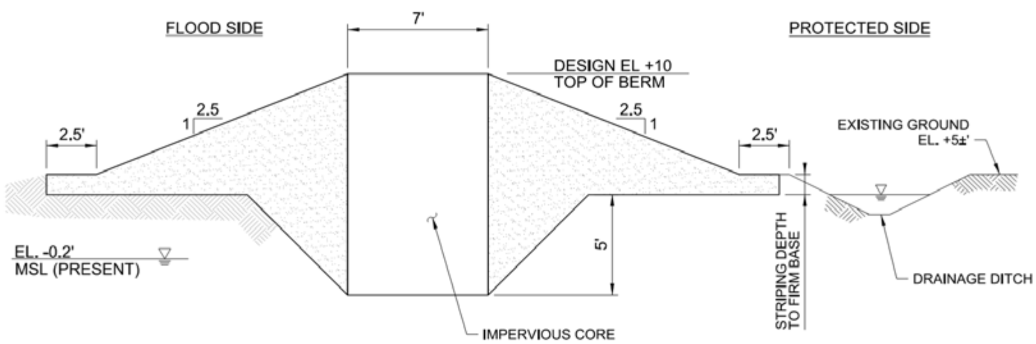

Figure 3-26: RRF Medium Berm Cross-Section

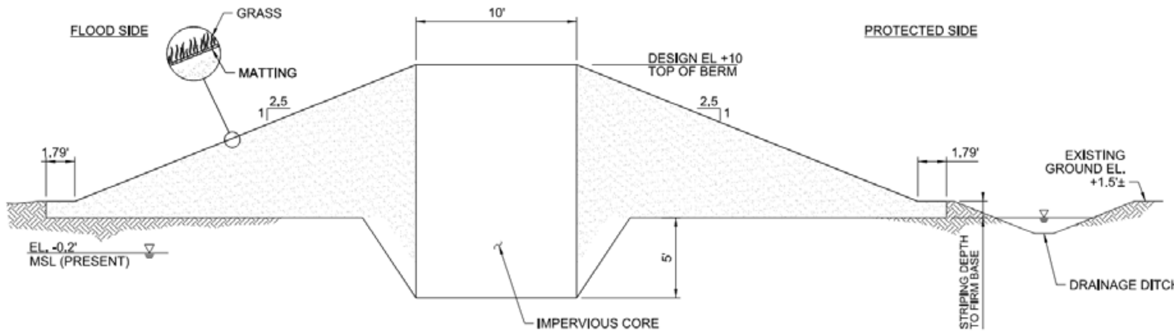

Figure 3-27: RRF High Berm Cross-Section

3.5.3 RRF – Hybrid Berm

As explained in Section 3.5.2, in general, berms integrate well into the natural landscape but have a relatively large footprint. In areas where a regular berm as an RRF would be appropriate, but a lack of available real estate renders the option impractical; a hybrid berm was used. The hybrid berm has the aesthetic advantage of a regular berm on the land side as well as the benefit of a reduced footprint. The hybrid berm is comprised of a berm on the land side, riprap on the flood side, and a vertical steel sheet pile wall in the middle. The steel sheet pile wall is equipped with a reinforced concrete pile cap that runs flush with the top of the berm. Since the sheet pile wall will act against any seepage concerns, the impervious core has been replaced with regular earth. The riprap with a slope of 1 vertical on 2 horizontal was used to provide scour protection. Similar to the low, medium, and high berms, a land side berm slope of 1 vertical on 2.5 horizontal was used. The hybrid berm has a crest width of 5 feet, a design height of 3.5 feet, and a design existing ground elevation of El. +6.5'. Figure 3-28 shows the typical cross-section of a hybrid berm.

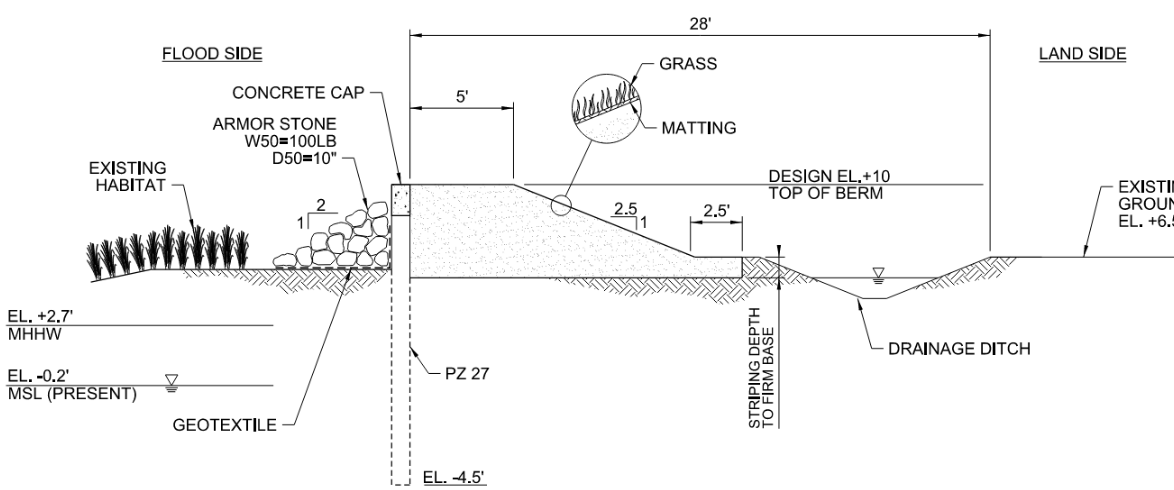

Figure 3-28: RRF Hybrid Berm with Floodwall Cross-Section

3.5.4 RRF – Shallow Bulkhead and Deep Bulkhead

A bulkhead wall typically comprises a steel sheet pile wall with or without a pile cap. The sheet pile wall is a row of vertical interlocking piles driven to form an integrated straight wall. Figure 3-29 shows an example of a bulkhead with concrete cap in Brooklyn, New York.

For this study, the bulkhead wall consists of a steel sheet pile wall and a reinforced concrete pile cap. On the land side, the concrete cap extends down from El. 10 feet to the existing ground elevation at El. 6 feet. A concrete splash pad at design ground elevation was provided for scour protection. Backfill was provided to fill in the gap between the new sheet piling and the existing bulkhead/shoreline.

While the main function of a bulkhead is usually to retain and prevent sliding of land, if vertically extended beyond existing grade and constructed watertight, bulkheads can also reduce the risk of upland flooding. Bulkheads on poor soil require longer sheet pilings. Because flood-prone waterfront areas in NYNJHAT Study are likely to have poor soil material, it was assumed that the soil in front of the sheet piling is characterized by poor sand. Soil behind the sheet piling was assumed to be backfill of medium sand up to existing ground elevation. Two different existing mudline elevations, El. -4 feet and El. -9 feet, were used to establish the design of the prototypical shallow and deep-water bulkhead as RRFs, respectively. This was done to capture the varying conditions throughout the NYNJHAT Study Area in which bulkheads would be applied as generic measure. The deeper the water (lower mudline elevation), the heavier and longer the sheet piling required. Sheet size and length for the shallow and deep bulkheads are shown in Figure 3-30 and Figure 3-31.

The relatively small footprint of a bulkhead renders it as a preferred solution to urban or developed waterfront areas that are subjected to flooding. At some locations, the waterfront can be characterized by a series of discontinuous and heterogeneous existing bulkheads that are privately owned with limited real estate for new structures. Manhattan Beach (Queens), Coney Island (Queens), and Broad Channel (Queens) neighborhoods are just a few examples where such conditions exist. In order to develop a prototypical feature, as in the case of bulkhead construction, the existing bulkhead structure is assumed to be non-functional because privately-owned bulkheads typically have no comprehensive maintenance program in place and hence likely experience some deterioration.

Figure 3-29: Bulkhead at South 5th Street Brooklyn, NY (M&N)

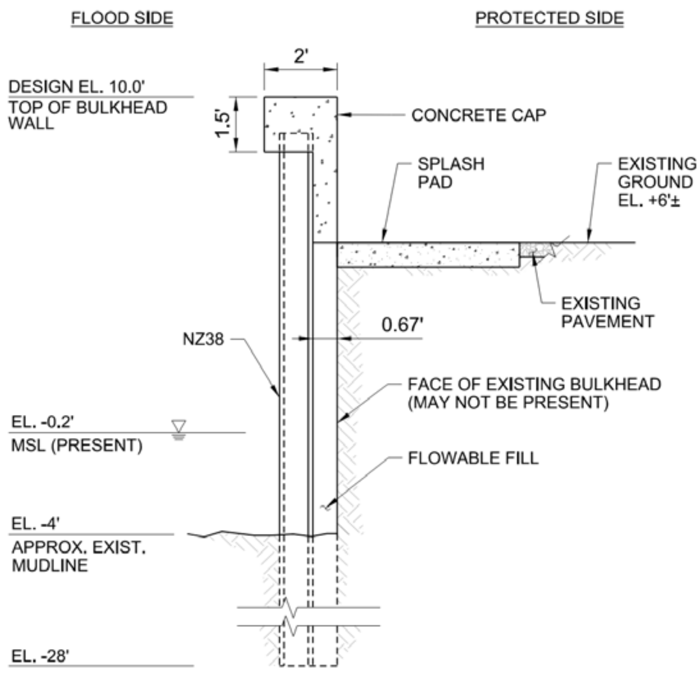

Figure 3-30: RRF Shallow Bulkhead Cross-Section

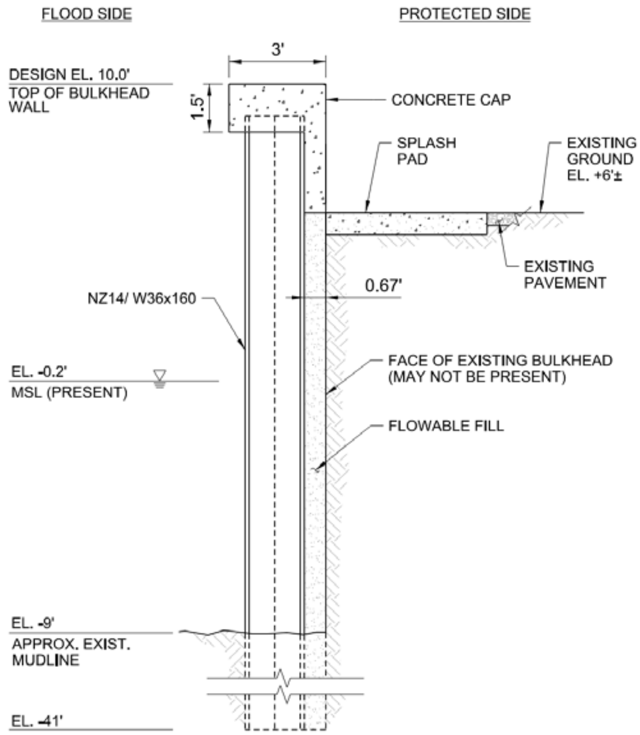

Figure 3-31: RRF Deep Bulkhead Cross-Section

3.5.5 RRF – Revetment with Floodwall

Revetments are onshore structures made of erosion-resistant material, such as stone or concrete. They are typically built to protect the shoreline from erosion. Revetments are comprised of an armor layer, filter layer(s), and toe protection. The armor layer is designed to maintain the revetment's cross-section during wave action. The filter layer supports the armor, reduces reflection (thereby increasing stability), and allows passage of water while retaining the underlying soil. The toe is to provide stability against undermining at the bottom of the structure. Figure 3-32 shows an example of a revetment in Hunter's Point New York City.

Figure 3-32: Revetment at Hunters Point, NY (photo credit: Nicole Avella)

Based on the general site condition, it was determined that a preliminary revetment design with a 2-foot diameter armor stone, 10-inch diameter underlayer stone, 1.3-foot diameter toe armor stone and a slope of 2 (Horizontal):1(Vertical) would provide sufficient stability. The protective rock armor serves to hold the revetment in place and consists of two layers of rock. The underlayer acts as a drain parallel to the slope to prevent a build-up of water pressure under the armor layer and a filter to prevent the underlying soil from washing out. The underlayer is on top of a geotextile. Toe protection is normally an integral part of the revetment structure and was designed to prevent the structural component from undermining as a result of wave and/or current-induced scour. The toe is comprised of two layers of toe armor stone with a width of 3.5 feet. The revetment, whereas effective at dissipating wave energy, cannot prevent coastal flooding since it is porous. Hence, an impervious concrete floodwall is installed on the landward side of the revetment to prevent flooding. The floodwall comprises a concrete cap and steel sheet piling. The top of the floodwall is at El. 10 feet and the design existing ground elevation is at El. 6.5 feet. The cross-section of revetment with floodwall is shown in Figure 3-33.

One of the more important variables of the revetment design is the seaward side slope, which, together with the crest height, is generally dictated by soil conditions and revetment construction methods. For the purposes of this study, it was assumed that the revetment was founded on reasonably good quality soils, which would not require foundation/ground improvements. The bottom elevation of the revetment was assumed to be at El. -7.5 feet. Actual elevations will vary across the study area, but for feasibility-level analysis it was considered a reasonable elevation for the revetment toe in the NYNJHAT Study Area.

Revetments integrate well with the natural shoreline with their natural look.

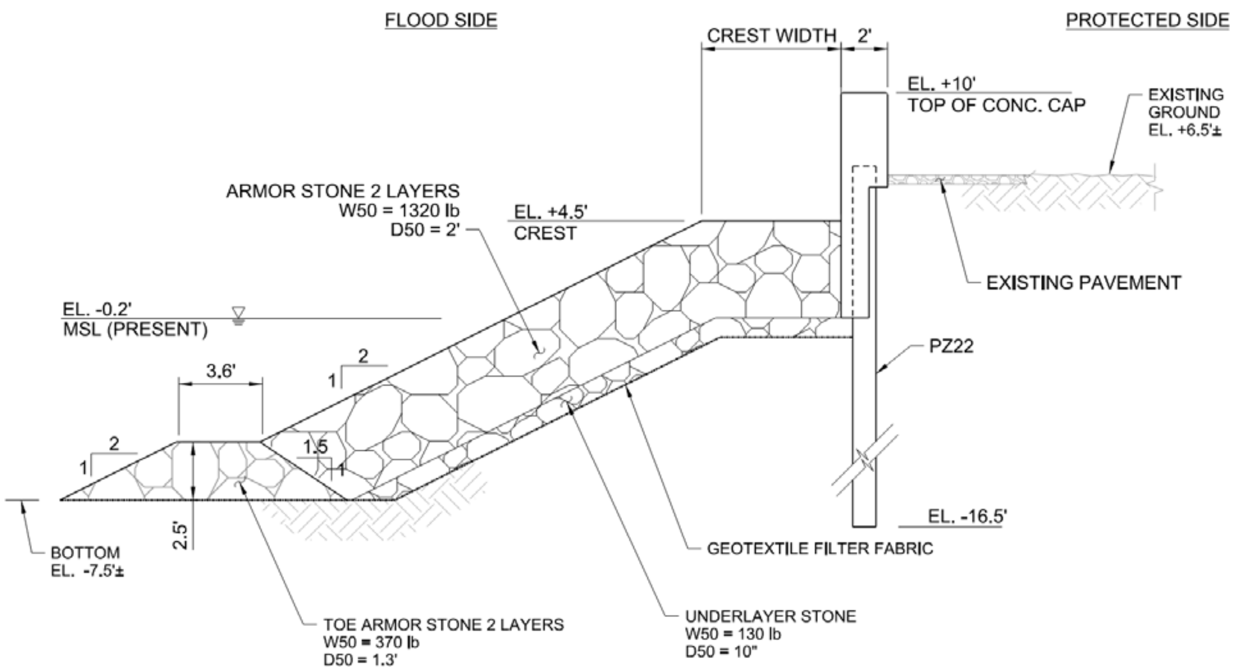

Figure 3-33: RRF Revetment with Floodwall Cross-Section

3.5.6 RRF – Pedestrian and Vehicular Gates

As discussed in Section 3.4.8, pedestrian and vehicular gates are features that allow unimpeded pedestrian and vehicular access across a road or driveway during normal day-to-day condition yet provide flood risk reduction when installed in conjunction with other flood risk features.

The gates can be either manually or automatically operated. The RRF prototypical vehicular gate is designed to be manually operated. Manually operated gates require operations personnel to physically go to the location of the gate and close it during storm conditions. The gate would then be locked into place to prevent tampering.

At this stage of the study, no preferred floodgate type has been selected, both swing gates and roller gates were considered. Both gates have the advantage of simple and quick operation where no special skill or equipment is required. However, a roller gate requires a larger level storage area immediately adjacent to the closure opening and a smaller operational right-of-way area than a swing gate.

Based on the generic site data gathered for the study areas, the prototypical vehicular gates have a gate width of 30 feet, a gate height of 4 feet, and a top of gate elevation of 10 feet. The gate foundation consists of concrete slab, steel sheet pile cut-off wall, and steel H-piles. Pile design depends on design loads and soil parameters. Since flood-prone waterfront areas are likely to have poor soil conditions, excavation and backfilling prior to construction may be required. It should be noted that only an inventory of the total number of gates will be completed for this study. Floodgate-type evaluation, gate size requirement, and associated detailed design would be completed during the next phases of the study when site-specific parameters are available. Figure 3-34 shows the typical cross-section of a vehicular swing gate.

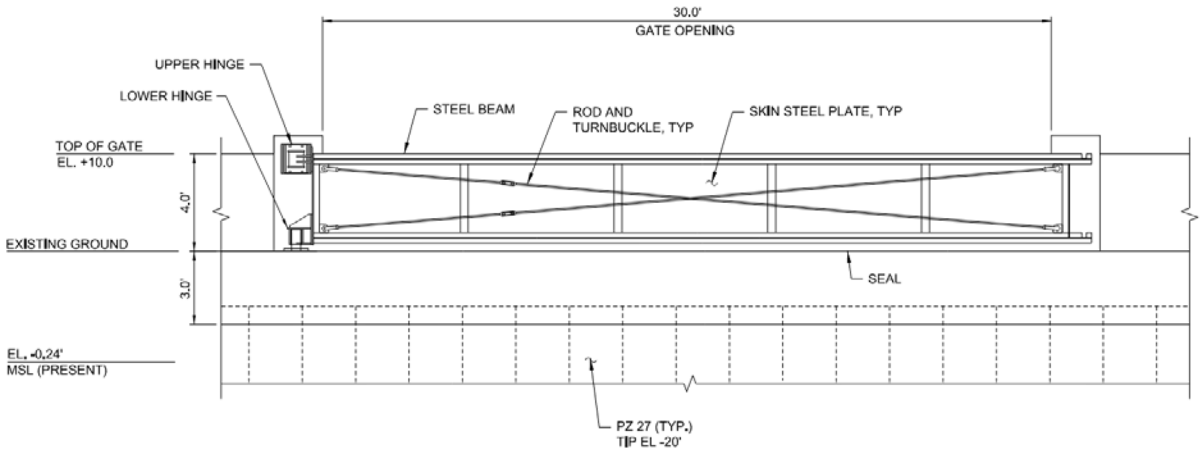

Figure 3-34: RRF Swing Gate Cross-Section

3.5.7 RRF – Tide Gate

General descriptions of the tide gate can be found in Section 3.4.9. Tide gates developed as SBMs function identical to those developed as RRFs. The main difference between the RRF tide gate and the SBM tide gate is the structure crest elevation, where the RRF tide gates are much lower in height with a crest elevation at10 ft NAVD88.

The tide gate has a sill elevation of -4 feet and a top of wall elevation of +10 feet. The prototypical tide gate developed for this study is designed to be provided with an electric winch and to be manually operated remotely. Figure 3-35 shows the typical cross-section of the tide gate.

The tide gates were assumed to be supported on piles. Pile design depends on design loads and soil parameters. Since flood-prone waterfront areas are likely to have poor soil conditions, excavation and backfilling prior to construction may be required. At this stage of the study, no preferred tide gate type has been selected. Tide gate type evaluation and associated detailed design would be completed during the next phases of the study when site-specific parameters are available.

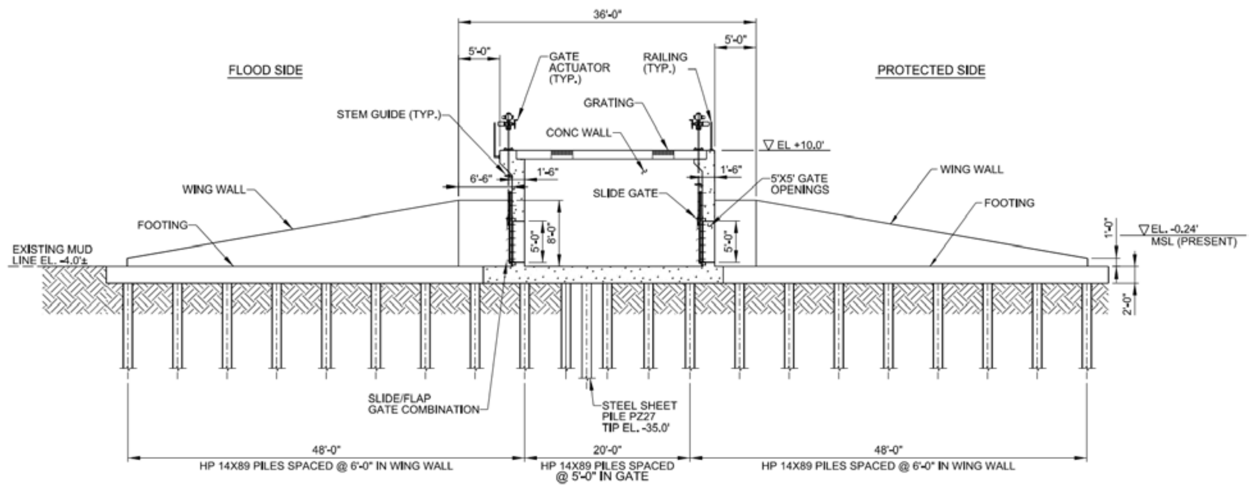

Figure 3-35: RRF Tide Gate Cross-Section

3.5.8 RRF – Road Raising

Road raising consists of raising an existing road's surface elevation in order to use the road itself as a berm-like feature, thus reducing the risk of flooding on one side of the road. In order to raise the road surface, any connecting driveway or side street needs to be raised and ramped to meet the raised road. In addition, buried retaining walls are used to support the increased height of the roadway. The various construction activities required to complete the road raising often necessitate relocating and/or raising buried utilities and adding drainage inlets and pipes at the bottom of driveways to convey stormwater away from homes and businesses. Figure 3-36 shows a prototypical section for the road raising feature.

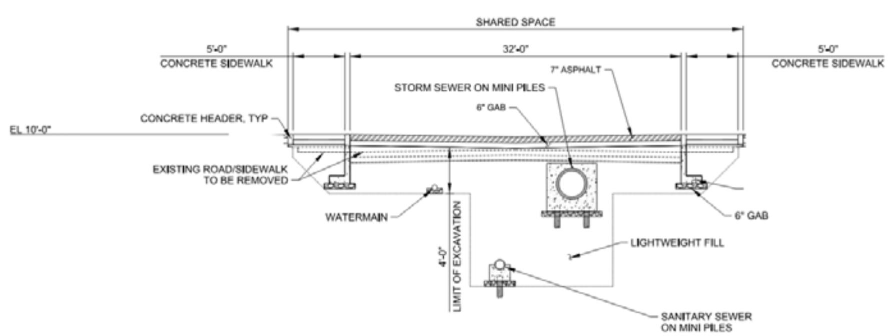

Figure 3-36: RRF Road Raising Cross-Section

3.5.9 RRF – Road Ramp

The road ramp comprises two drive lanes and can be designed with sidewalks to allow for safe pedestrian access. The road ramps for this project were designed to be used in conjunction with low floodwalls on either side. In order to allow a vehicle towing a boat to use the ramps without bottoming out, a design length of 85 feet from the bottom of either end of the ramp was used. A culvert would be put under the road ramp to convey drainage to nearby outfalls/pump stations, as needed. A typical cross-section of a road ramp is shown in Figure 3-37.

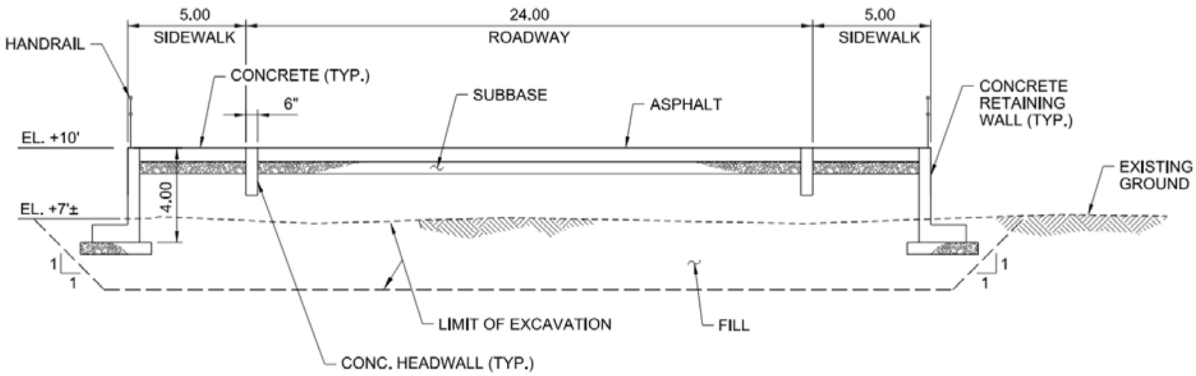

Figure 3-37: RRF Road Ramp Cross-Section

3.6 Easements

Real estate requirements, including easements, were estimated through definitions of SBM alignment footprints. The easements footprints are used by the USACE NAN Real Estate (RE) division for cost estimates. Two types of easements are distinguished for the NYNJHAT Study alignments: (Perpetual) flood risk reduction easements, and Temporary work area easements. The Temporary Work Area Easement has been established to allow for all construction, staging, grading, landscaping, and other construction-related activities. The Temporary Work Area Easement will remain active until final acceptance and contractor demobilization. The Perpetual Easement will be established to allow the SBMs to be inspected and maintained. It is permanent in nature, and USACE will have the right to use the land within the easement lines. All easement limits provided herein are preliminary in nature and used for feasibility study purposes. Given the study alignment's close proximity to private property, siting studies, additional refinements, realignments, and site-specific details will need to be developed in the next phase.

3.6.1 Perpetual Easements

Based on previous experience and USACE NAN projects within the region, as well as guidance taken from ETL-1110-2-583 (which details the requirements for vegetation-free and vegetation-managed zones), it is proposed to include a 15-ft perpetual easement from the levee embankment toe or structure toe location, and to include a 15-ft perpetual easement from the face of the flood wall or an 8-ft distance from justifiable sub-grade toe locations, i.e., extent of floodwall foundation or limits of drainage appurtenances. Following this methodology, perpetual easement distances are rounded up to the nearest foot.

3.6.2 Temporary Work Area Easements

Based on previous experience and USACE NAN projects within the region, it is proposed to include a 50-ft wide temporary work area easement. The easement distance (rounded up to nearest 5 ft) is calculated by offsetting the centerline at least 25 ft, while making sure that the perpetual easement falls within this distance.

A typical depiction of perpetual and temporary easements for a medium 7 ft floodwall is shown in Figure 3-38. The perpetual easement for this example equates to 32 ft and consists of a 15-ft distance for maintenance access on the floodside taken from the floodside toe of the wall (this coincides with the centerline for this structure). On the land side, the 8-ft offset from the appurtenance sets the maintenance access distance at 17 ft from the centerline. The temporary work easement, needed for construction equipment and supplies, equates to 50 ft consisting of a 25-ft offset from the centerline on both the flood side and the land side.

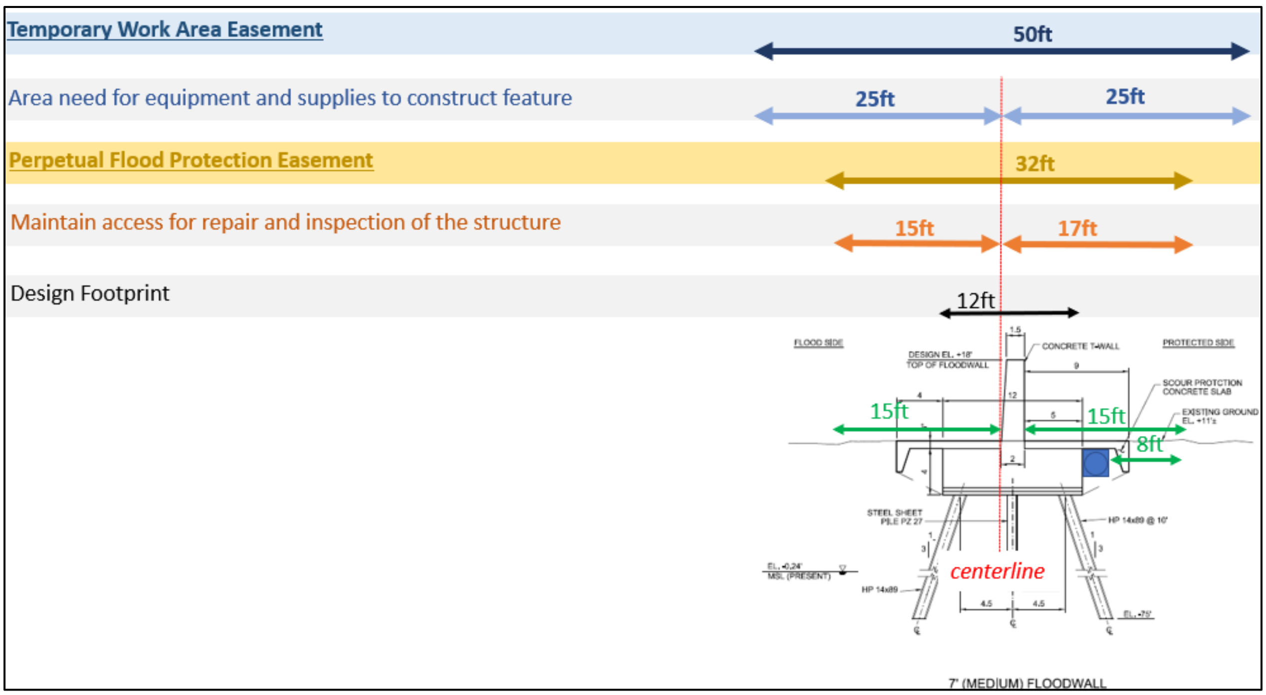

Figure 3-38: Easements for a Medium Floodwall with a 7 ft reveal height

Easements for SBMs are summarized in Table 3-4 and for RRFs in Table 3-5 below.

Table 3-4: SBM Easements – perpetual and temporary work easement distances are taken from structure centerline as shown in Figure 3-38

Easement Description		Extra Large Floodwall	Large Floodwall	Medium Floodwall	Large Levee	Medium Levee	Elevated Promenade	Floodwall with Park	Seawall	Reinforced Dune – Natural Dune Cover	Reinforced Dune – Partial Dune Cover	Deployable Flood Barrier – Flip Up Barrier	Deployable Flood Barrier – Vehicle Gate	Deployable Flood Barrier – Pedestrian Gate	Deployable Flood Barrier – Railroad Gate	Tide Gate
Area for Maintenance	Flood Side [ft]	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	Protected Side [ft]	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Perpetual Easement	Flood Side [ft]	15	15	15	64	44	50	15	61	52	52	25	23	23	23	73
	Protected Side [ft]	19	18	17	77	55	45	18	24	45	45	25	23	23	23	73
Temporary Work Area Easement	Flood Side [ft]	25	25	25	65	45	50	25	65	55	55	25	25	25	25	75
	Protected Side [ft]	25	25	25	80	55	45	25	25	45	45	25	25	25	25	75

Table 3-5: RRF Easements – perpetual and temporary work easement distances are taken from structure centerline as shown in Figure 3-38

Area for Maintenance	Flood Side [ft]	15	15	15	15	15	15	15	15	15	15	15	15	15	15	5
	Protected Side [ft]	15	15	15	15	15	15	15	15	15	15	15	15	15	15	5
Perpetual Easement	Flood Side [ft]	18	15	15	29	34	15	44	17	18	52	30	20	20	73	20
	Protected Side [ft]	15	17	19	40	43	43	55	15	15	20	30	20	20	73	20
Temporary Work Area Easement	Flood Side [ft]	25	25	25	30	35	25	45	25	25	55	30	25	25	75	20
	Protected Side [ft]	25	25	25	40	45	45	55	15	15	25	30	25	25	75	20

4 Inventory of SBMs for NYNJHAT Study Alternatives

4.1 Introduction

The previous section presented the preliminary designs for the SBMs and RRFs developed for the NYNJHAT Study. Due to the large area covered by the NYNJHAT Study and the varying coastal edge conditions associated with the design of the SBMs, the designs are preliminary in nature yet sufficient to establish a quantity take-off of construction materials. The preliminary designs presented in the previous section, in combination with the refinement of the alignments, allows for an inventory of all structural SBM, IFF, and RRF measures under the NYNJHAT Study. The inventory is separated into two data sets:

1) Quantity take-off per SBM and RRF, and

2) Inventory of number and length of SBMs, IFFs, and RRFs per alternative.

These two data sets are then used to complete cost estimates for the study alternatives and allow for a comparison amongst the alternatives. The reader is referred to the Cost Engineering Appendix and the Economics Appendix for that information.

4.2 Quantities and Inventory of Shore-Based Measure

4.2.1 Quantity Take-offs

Quantity take-offs per linear foot were developed for each prototypical SBM, with the exception of the deployable vehicular, pedestrian, and railroad gates. The quantity per linear foot of the medium floodwall SBM is shown in Table 4-1 as an example. Annex F includes the quantity per linear foot for all SBMs and RRFs. For gates and tide gates, the total count of structures per alternative is also provided (Table 4-3 to Table 4-5). Additional appurtenances were described qualitatively instead of quantitively, and additional caveats and notes regarding the items covered within each quantity take-off are listed in Annex F.

Table 4-1: Quantity per Linear Foot of Medium Floodwall

Medium Floodwall		
Item	Quantity per linear foot	Unit
Reinforced Concrete for Flood Wall and Splash Aprons	3.00	CY
PZ-27 Sheetpile Wall	0.27	TN
HP 14x89 Piles (89' Long)	17.80	LF
Excavation	3.15	CY
Repair Disturbed Pavement	0.11	SY
Additional Appurtenances: The items below are outside of the core construction quantities but should still be considered in the cost estimate. Ladders/Stairs with handrail to provide access to flood side and aid inspection Transitions between feature types Utility relocation, drainage features, aesthetic features, real estate, right-of-way, easement, environmental mitigation		

4.2.2 Inventory of SBMs, IFFs, and RRFs per Alternative

The NYNJHAT Study Alternatives were described in Section 1.3. Each SBM alignment, depending on the existing site conditions, may comprise one or more preliminary SBMs (including SBMs, IFFs, and RRFs). Based on the SBM type and the proposed length for each SBM included within each reach, an inventory was developed per alternative on a reach basis. For example, the Kill van Kull barrier Tie-In (Separated) reach includes 206 feet of vehicular gate (over 2 gate locations), 67 feet of railroad gate (1 gate location), 178 feet of medium floodwall, and 2,048 feet of large floodwall with a total length of 2,499 feet (see Table 4-2). Detailed inventory tables can be found in Annex E.

Table 4-2: Excerpt of Summary Table of SBM Length for Kill Van Kull Barrier Tie-in

	Medium Floodwall (feet)	Large Floodwall (feet)	Railroad Gate (feet)	Vehicle Gate (feet)	Grand Total (feet)
Kill Van Kull Barrier Tie-In Separated	178	2048	67	206	**2499**

An inventory of SBMs, IFFs, and RRFs for each alternative were determined and are shown in Table 4-3 to Table 4-5. These tables include measure lengths in miles for all SBMs, IFFs, and RRFs and measure counts for the deployable features (flip-up barriers, pedestrian gates, etc.) and tide gates. Measure counts were added specifically for the deployable features and tide gates since cost estimates were performed per each individual structure for these features (otherwise per linear distance for the remaining features). Diagrams depicting the tabulated information are provided in Figure 4-1 to Figure 4-3.

Table 4-3: Summary Table of SBMs, Length and Count for Each Alternative

Function	Features	Alt. 2 in Miles (Count)	Alt. 3A in Miles (Count)	Alt. 3B in Miles (Count)	Alt. 4 in Miles (Count)	Alt. 5 in Miles (Count)
SBM	Medium Floodwall	–	2.0	4.0	5.3	1.0
SBM	Large Floodwall	0.6	3.3	10.8	11.9	3.7
SBM	Extra-large Floodwall	–	–	3.1	2.7	2.6
SBM	Medium Levee[1]	–	2.8	3.7	5.6	0.6
SBM	Large Levee[1]	0.3	1.5	4.9	5.0	15.3
SBM	Elevated Promenade	–	2.6	8.5	8.5	5.6
SBM	Floodwall with Park Integration	–	–	0.6	0.6	0.3
SBM	Seawall	–	2.4	5.9	5.9	1.1
SBM	Reinforced Dune with Natural Dune Cover	10.2	0.8	0.8	0.8	–
SBM	Reinforced Dune with Partial Dune Cover	13.2	6.9	6.9	6.9	–
SBM	Flip-up Barrier	–	–	0.3 (4)	0.3 (4)	0.3 (4)
SBM	Pedestrian Gate	–	0.0	0.3 (53)	0.3 (54)	0.3 (49)
SBM	Vehicular Gate	0.1 (4)	0.2	0.7 (64)	0.7 (63)	0.4 (36)
SBM	Railroad Gate	–	–	0.1 (4)	0.1 (4)	0.1 (5)
SBM	Tide Gate	–	0.1	0.1 (1)	0.1 (3)	0.1 (2)
Total		**24.2**	**22.7**	**50.6**	**54.7**	**31.1**

Notes:

1. Road ramps are included with some levee segments: 3 road ramps in alternative 2, 7 in alternative 3A, 10 in Alternative 3B, 11 in alternative 4, and 15 road ramps in Alternative 5.

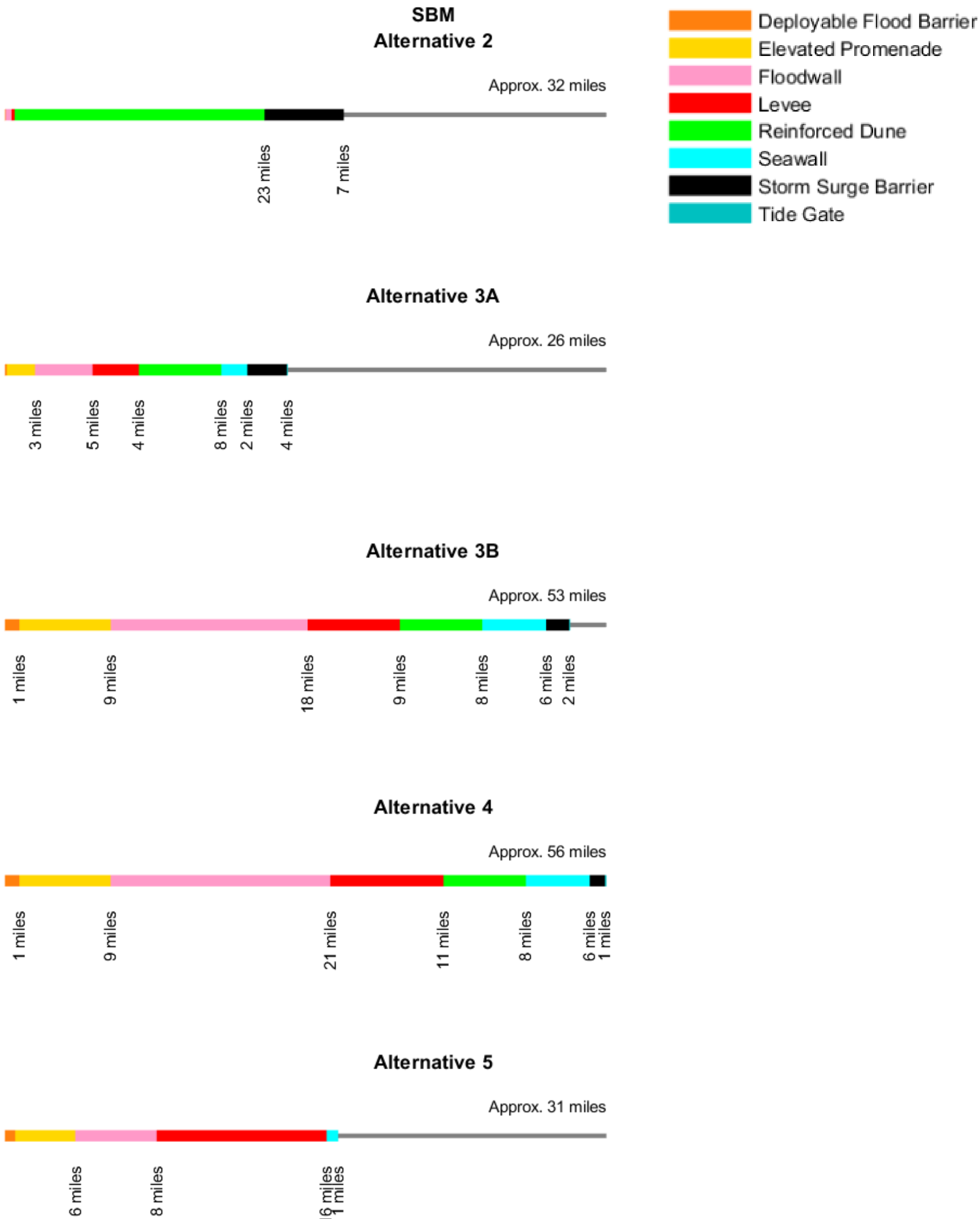

Figure 4-1: Diagram Depicting SBM Length for NYNJHAT Study Alternatives

Table 4-4: Summary Table of IFFs, Length and Count for Each Alternative

Function	Features	Alt. 2 in Miles (Count)	Alt. 3A in Miles (Count)	Alt. 3B in Miles (Count)	Alt. 4 in Miles (Count)	Alt. 5 in Miles (Count)
IFF	Medium Floodwall	–	–	0.04	2.3	–
IFF	Large Floodwall	1.1	4.3	2.5	21.3	–
IFF	Extra-large Floodwall	3.0	3.8	0.8	4.1	–
IFF	Large Levee	5.8	18.1	2.4	4.5	–
IFF	Elevated Promenade	0.5	1.3	0.5	–	–
IFF	Seawall	11.8	15.7	0.6	3.7	–
IFF	Reinforced Dune with Natural Dune Cover	0.2	3.4	3.1	3.1	–
IFF	Reinforced Dune with Partial Dune Cover	–	4.5	1.7	1.7	–
IFF	Pedestrian Gate	–	0.01 (4)	–	–	–
IFF	Vehicular Gate	0.04 (5)	0.2 (19)	0.1 (10)	0.5 (51)	–
IFF	Railroad Gate	–	–	–	–	–
IFF	Tide Gate	0.3 (12)	0.3 (15)	–	0.1 (3)	–
Total		**22.5**	**51.5**	**11.8**	**41.4**	**–**

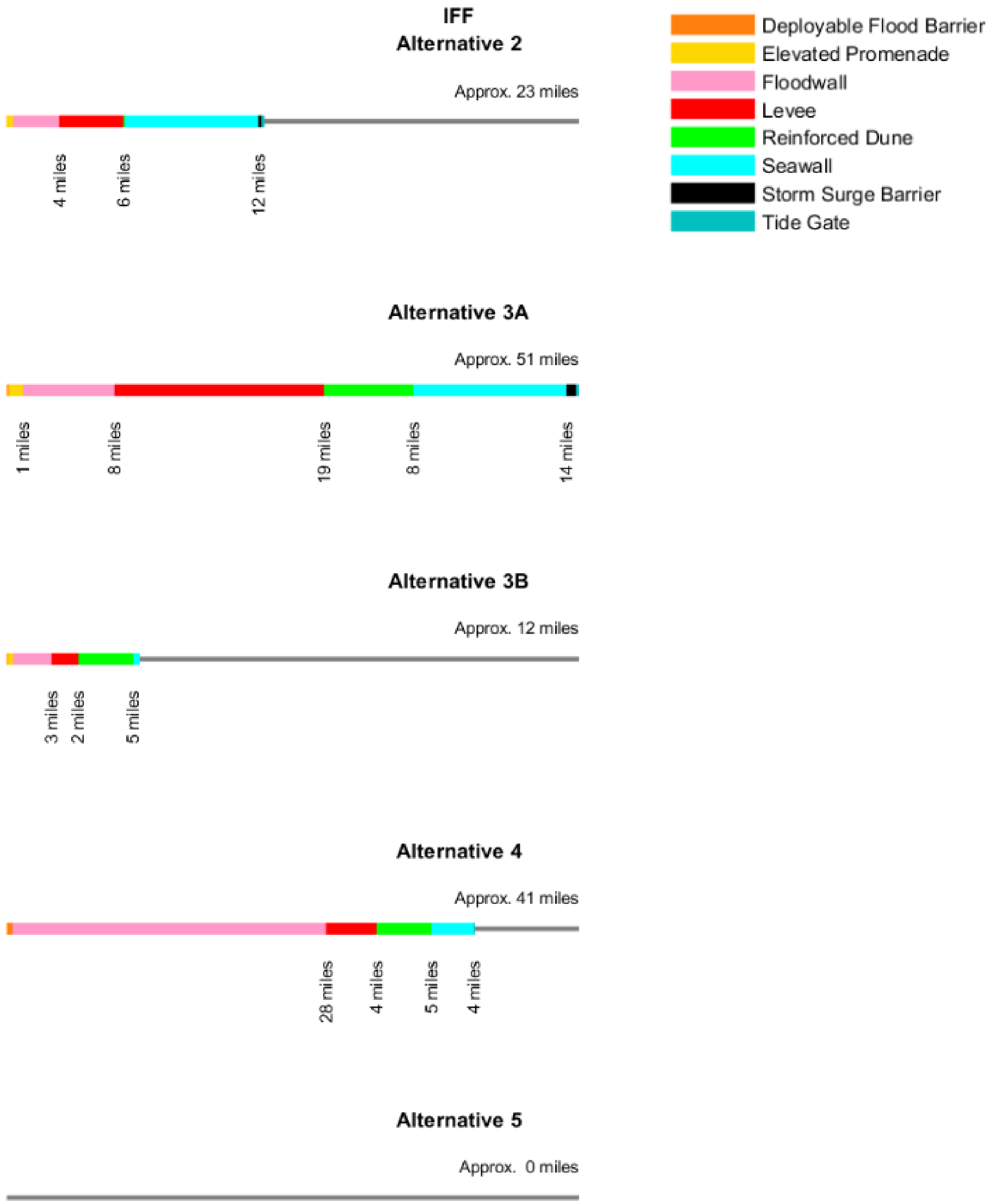

Figure 4-2: Diagram Depicting IFFs Length for NYNJHAT Study Alternatives

Table 4-5: Summary Table of RRFs, Length and Count for Each Alternative

Function	Features	Alt. 2 in Miles (Count)	Alt. 3A in Miles (Count)	Alt. 3B in Miles (Count)	Alt. 4 in Miles (Count)	Alt. 5 in Miles (Count)
RRF	Low Floodwall	5.5	4.8	2.4	0.5	–
RRF	Standard Floodwall	5.4	5.3	4.1	1.1	–
RRF	High Floodwall	1.0	1.0	1.0	0.3	–
RRF	Low Berm	1.9	1.6	1.6	1.5	–
RRF	Medium Berm	2.9	0.7	0.7	–	–
RRF	High Berm	0.8	0.8	0.4	0.3	–
RRF	Hybrid Berm	0.1	0.02	0.02	–	–
RRF	Shallow Bulkhead	3.7	3.4	3.4	3.4	–
RRF	Deep Bulkhead	8.9	5.3	1.2	0.2	–
RRF	Revetment with Floodwall	3.9	2.4	2.4	0.2	–
RRF	Pedestrian Gate	0.03 (9)	0.03 (9)	–	–	–
RRF	Vehicular Gate	0.3 (17)	0.2 (16)	0.04 (4)	0.02 (2)	–
RRF	Tide Gate	0.1 (5)	0.1 (4)	0.04 (3)	–	–
RRF	Road Raising	0.9	0.9	0.9	0.9	–
RRF	Road Ramp	0.01 (2)	0.01 (2)	0.01 (2)	0.01 (2)	–
Total		**36.2**	**27.1**	**18.7**	**8.5**	**–**

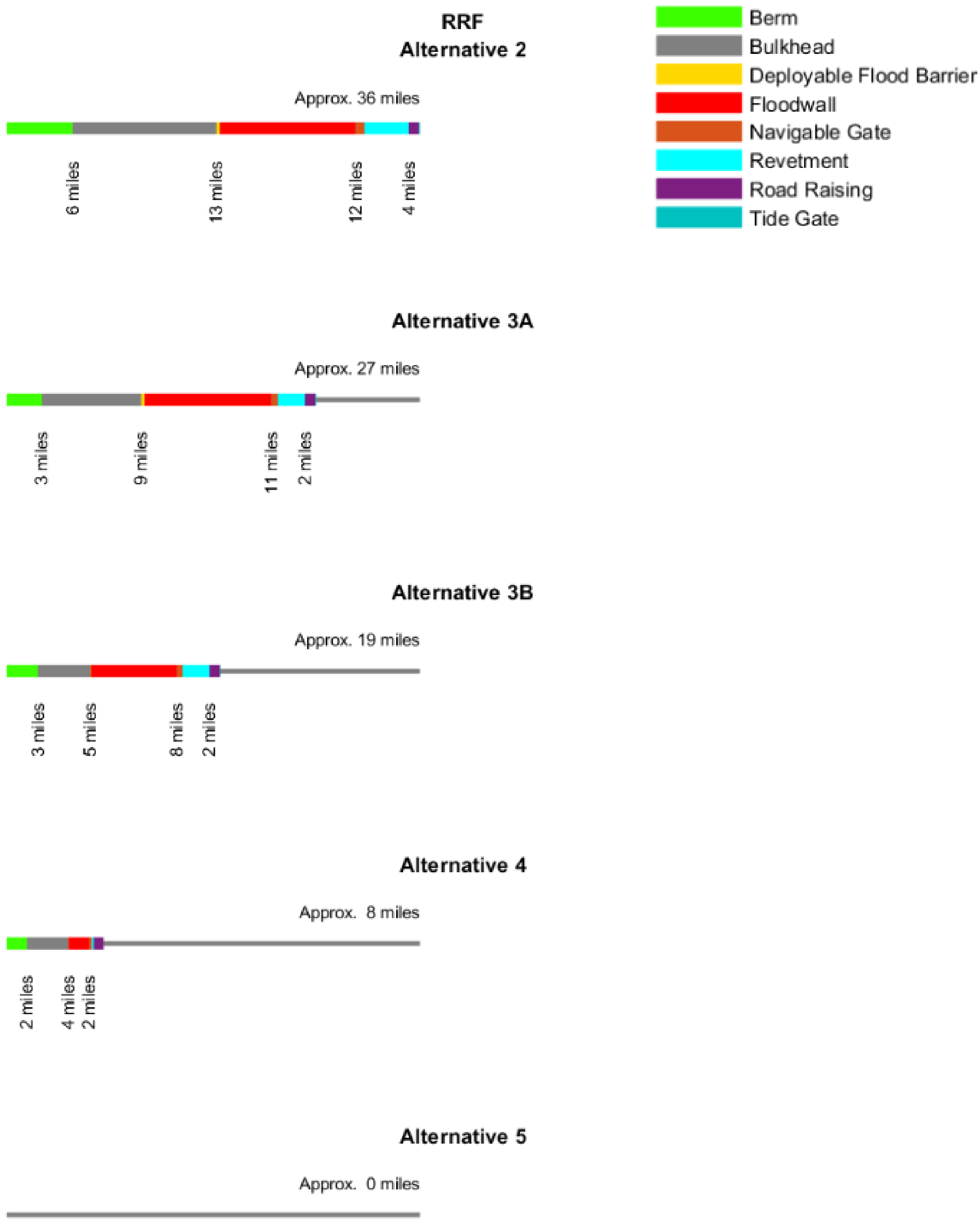

Figure 4-3: Diagram Depicting RRFs Length for NYNJHAT Study Alternatives

Maps of the NYNJHAT Study alternatives that show the SBM, IFF, and RRF alignments are included in Annex D.

Table 4-6 shows an overview of the breakdown of SBM lengths for each alternative. Alternative 4 has the greatest total length of SBMs.

Table 4-6: Summary Table of Lengths of SBMs, IFFs, and RRFs for Each Alternative in Miles

Shore-Based Measures	Alt. 2	Alt. 3A	Alt. 3B	Alt. 4	Alt. 5
SBM	24.2	22.7	50.6	54.7	31.1
IFF	22.5	51.5	11.8	41.4	–
RRF	36.2	27.1	18.7	8.5	–

5 Summary and Recommendations for Further Study

5.1 Summary

The New York/New Jersey Harbor and Tributaries Study Area was identified as a focus area within the North Atlantic Coast Comprehensive Study. As discussed in Section 1.3, five NYNJHAT Study Alternatives were developed for evaluation. Preliminary coastal storm risk management measures, including storm surge barriers and shore-based measures, were developed based on the general design criteria (Section 1.4) for the NYNJHAT Alternatives. This sub-appendix focuses solely on the SBMs; storm surge barriers are covered under separate cover in the SSB sub-appendix and hence not discussed herein.

The NYNJHAT Feasibility Report includes the terms SBM, IFFs, and RRFs when describing structural coastal storm risk management measures at the shoreline or on land. These SBMs, IFFs, and RRFs are the focus of this appendix. A brief description of each term and the flood risk associated with each is provided in Table 5-1 below.

Table 5-1: Shore-Based Measures Terminology

Acronym	Term	Description	Mitigated Flood Risk
SBM	Shore-Based Measure	SBMs are designed to provide flood risk reduction for 100-year Return Period (RP) storm events (1% Annual Exceedance Probability (AEP)) in 2095 for areas that are not protected by storm surge barriers. The alignments of SBMs (as defined in Section 1.2) for each study alternative was developed by USACE, with small modifications by the A/E where appropriated.	1% AEP flood level
IFF	Induced Flooding mitigation Feature	IFFs are equal and equivalent to SBMs and are only distinguished as IFFs because they provide flood risk reduction for areas subject to induced flooding.	1% AEP flood level
RRF	Risk Reduction Feature	Where storm surge barriers are proposed (Alternatives 2, 3A, 3B, and 4), complementary measures to manage the risk of frequent flooding are also proposed. RRFs mitigate residual flood risk under the assumption that the storm surge barrier (SSB) closure criterion is El. +7 ft NAVD88.	+7ft NAVD88 flood level

This appendix documents the general design criteria and preliminary design for the shore-based measures which are part of the NYNJHAT Study's structural flood risk reduction measures. The purpose of the study is to develop generalized SBMs that are comprehensive enough to be applicable and suitable for the entire study area yet not too detailed or site-specific that they could only be applied at one location.

The alignments for the NYNJHAT Study Alternatives are presented in Annex D and each Alternative includes a variety of measures that make up the SBM, IFF, and RRF alignments. As part of the NYNJHAT Study, the following SBMs and RRFs were developed and presented herein:

<u>SBMs</u>:

- Floodwalls
  - Medium Floodwall
  - Large Floodwall
  - Extra Large Floodwall
- Levees
  - Medium Levee
  - Large Levee
- Elevated Promenade
- Floodwall with Park Integration
- Seawall
- Reinforced Dune
  - Reinforced Dune – Natural Dune Cover for natural shoreline application, and
  - Reinforced Dune – Partial Dune Cover for urban application
- Deployable Flood Barriers
  - Flip-up Barrier
  - Pedestrian, Vehicular and Railroad Gates
- Tide Gate

<u>RRFs</u>:

- Floodwalls
  - Low Floodwall
  - Standard Floodwall
  - High Floodwall
- Berm

  - Low Berm
  - Medium Berm
  - High Berm
  - Hybrid Berm,
- Bulkhead
  - Shallow Bulkhead
  - Deep Bulkhead
- Revetment with Floodwall
- Tide Gate
- Deployable Flood Barriers
  - Vehicular Gates and Pedestrian Gates
- Road Ramp
- Road Raising

The completion of the preliminary designs for these measures allowed for an inventory of shore-based measures (total length and number of measures) per NYNJHAT Study Alternative and for a quantity take-off per SBM. This data set was then used to complete cost estimates for the study alternatives (see Cost Engineering Appendix).

5.2 Recommendations

5.2.1 Recommendations for Alignment Refinements

The NYNJHAT Study Alternatives were based on the SBM alignments developed during plan formulation. Refinements and alterations to the SBM alignments were made over the course of the feasibility study to allow for better implementation of SBMs and incorporation of stakeholders' comments, but were generally minor. RRF alignments and IFF alignments were added to each study alternative where applicable during the feasibility study since those were not defined in the early plan formulation phase of the study.

In many instances, the alignment or the selection of the SBM relied on a high-level review of available data. It should be reiterated that no site-specific topographic survey, bathymetric survey, condition survey, and/or geotechnical analysis have been completed. Instead, in accordance with USACE's SMART planning principles, the alignment and the selection of the SBM type was based on qualitative data and a desktop-level analysis, which yield generalizations of existing conditions. It is understood that those further refinements will be completed at later stages of the study when additional time and resources can be focused on the most viable alternative or alternatives.

The implications of these assumptions are that further optimization of the alignment is possible and that for reaches where conflicts are most apparent, an alternative comparison on a reach-by-reach basis is recommended. In such a study, alternate alignments would be compared amongst each other and evaluated and screened using criteria such as, but not limited to, cost, constructability, and impacts. The following studies are recommended to further refine the alignment of the selected alternative in the post-TSP study phase or during PED:

1. Site topographic survey
2. Existing structure condition survey
3. Site-specific geotechnical data
4. Site-specific metocean study
5. Bathymetric survey for alignments following existing bulkhead lines
6. Site use and traffic studies
7. Wetland survey and mapping
8. Comprehensive interior drainage modeling
9. Continuation of stakeholder and public outreach such that input and comments from stakeholders can further inform alignment alternatives to be evaluated
10. An analysis of easement delineation and real estate studies such that impacts beyond the footprint of the measures can be preliminarily assessed
11. Utility investigations and as-needed service diversions or relocations studies
12. Cost Estimates and impact assessments for alignment alternatives
13. The Americans with Disabilities Act (ADA) and egress studies
14. Site hazardous studies
15. Optimization study for RRFs with various SSBs closure criteria

5.2.2 Recommendations for Further Design Refinements of SBMs

The preliminary designs for the SBMs are of sufficient detail to support quantity take-offs. The SBMs used here are limited to a total of twenty-seven (27) and are at a level of detail commensurate with a feasibility study. Assumptions, as discussed in the report, have been made to advance the design, but it should be noted that additional data and studies are needed for the next design phase to refine the SBM designs such that more site-specific measures can be developed for the recommended alternative(s). Recommendations for next phases of the project include:

1. Evaluate the need for refinement of the SBMs and development of additional site-specific SBMs.

2. Assess and design the transitions between various SBMs, transitions between SBMs and the existing high ground, and transitions between existing and proposed SBMs.

3. Assess and design transition from SBMs to existing high ground (tie-ins or tie-offs).

4. Refine the requirements for future adaptability and refine the SBM designs to incorporate adaptability into the design.

5. Setting the wave overtopping criterion and optimize it for the study. Ideally, the overtopping criterion is informed by two main considerations:

    a. The ability of the risk reduction system to handle the volume of overtopping (i.e., pumping or storage on the land side of the risk reduction alignment may allow for accepting large overtopping volumes), and

    b. The type of construction on the land side of the alignment, e.g., grey infrastructure has a relative high tolerance for large overtopping discharges prior to the onset of structural failure while levees have a lower tolerance. Given the urban nature of the study and relatively high portion of grey SBMs, a higher overtopping criterion could be considered.

6. Complete a gate-type evaluation. For locations where deployable flood gates and tide gates are required, determine the best gate types, sizes and, configurations.

7. Assess the control, security, and deployment requirements for the deployable flood barriers.

8. Evaluate the need for maintenance and inspections for each SBM.

9. Continuation and furthering stakeholder and public outreach such that input and comments from stakeholders – including city, state agencies, and the public – can be incorporated for better integration of the SBMs into the urban fabric.

10. Coordinate and provide supports for non-structural elements, such as lighting, conduits, landscaping, public amenities, and utilities.

Finally, albeit that major construction items have been accounted for in the quantity take-off, a number of items could only be qualitatively discussed, since insufficient information or data is available at this stage in the study to provide meaningful quantitative data. For the SBMs, additional data collection and studies should be completed such that existing data gaps can be filled and a more complete inventory of items and work form the basis of the cost estimates. Such items are detailed in Table 5-2.

Table 5-2: Detailed Design Work to be Considered During Next Phases of the Study

SBM Appurtenances and Construction Related Work Items	Example
Utility relocation	Gas, water, electricity, cable, etc.
Additional drainage features	Storm water pipes, channels, etc.
Additional aesthetic features	Pavers, textured wall, etc.
Additional access features	Ramps, railing, stairs, etc.
Additional non-structural items	Lighting, conduits, emergency phones, real estate, right-of-way, landscape, public amenities, easement quantities, environmental mitigation, CCTV, etc.
Upgrade	Strengthening of existing structural elements, upgrade of non-structural items, etc.

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Annexes