Raritan Bay and Sandy Hook Bay
Highlands, New Jersey
Coastal Storm Risk Management
Feasibility Study

Feasibility Report

May 2020

Appendix B5:
Structural

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Overview

The New York District of the U.S. Army Corps of Engineers formulated a variety of coastal storm risk management (CSRM) alternatives for the Highlands CSRM feasibility study in order to evaluate various goals such as maximizing the level of risk reduction, reduction of overtopping, maintaining access, waterfront views, or to eliminate the need for risk management all together. Engineering judgment and some general calculations were applied to refine each alternative type to be included in the Highlands project alignment. These alternatives included some variation of sheet pile walls, capped sheet pile walls, reinforced concrete walls, removable fabricated walls, different sizes of closure gates for access, and an offshore closure gate. The features were combined with other coastal storm risk management or avoidance measures in order to compare the cost benefit of each alternative.

The project extends for approximately 8000ft and includes most of the borough bay shoreline. The western portion will likely tie into high ground just before the privately owned area known as Harborside at Hudson's Ferry development. This area provides its own storm risk management system. The eastern portion will tie into high ground just before the Route 36 Highlands Bridge. Still water level (SWL) of +8.9' North American Vertical Datum of 1988 (NAVD88), plus a value of +1.1 feet for the hydrostatic wave force of small surface, wind generated inland waves, was used in the design of each flood risk reduction structure. Project wave action varied from West to East based on exposure to wind driven waves. Final wall heights were determined from overtopping rates based on wave height and frequency. Two overtopping criteria were used to set the crest elevations: the "critical values of average overtopping discharges" (defined by activity) and the "damaging/unsafe condition overtopping threshold rates". The crest elevations allow for modest overtopping without jeopardizing structural or public safety or introducing damage. The projections resulted in final wall elevations that varied between +12.4' NAVD88 generally near the western end of the project and +9.9 NAVD88 towards the eastern end.

During the optimization effort, the wall heights for the project were leveled to +11' NAVD88, +13' NAVD88 and +14' NAVD88. These optimization values were identified to determine economic benefits with the level of protection provided by each alternative. The optimized plan is described in chapter 5.

As with most any method of coastal storm risk management, runoff trapped behind the structure may affect the hydrology and drainage of interior areas. Considerations should be made to include methods to discharge the water behind any method of coastal storm risk management without weakening the coastal storm risk management system.

Chapter 1: Criteria

For the purposes of the study, general guidance from USACE Engineering Manuals was reviewed in order to generate preliminary wall sections. The draft EC 1110-2-6066 pertaining to I-wall design were also considered during the process, however due to the preliminary nature of the EC cited requirements were not included in this feasibility effort. For the optimization phase of this report, guidance from ETL 1110-2-575 was utilized. General principles and guidance based on existing projects was also used to estimate the size and type of flood risk reduction.

Chapter 2: Structure Types

Five basic types of structures were integrated in to the screened alternatives. Each provided its own benefit based on the goal/theme of the alternative. While the structure type would be modified per alternative, the basic concepts of each are as follows.

2.1 Seawall/Bulkhead Modification

This measure would entail raising or capping existing bulkheads. Raised bulkheads would provide risk reduction from coastal flooding to interior structures. Two general methods would be used for this type of coastal storm risk management system: sheet pile and capped existing sheet pile.

2.1.1 Sheet Pile

The sheet pile option is the main structural method for risk reduction for each alternative. Sheet pile will be driven into the ground along the required alignment and with the appropriate stick up to provide flood risk reduction. Sheet pile type and length will ultimately be sized based on loadings from the soil, water, and other boats and debris that could come in contact with the wall during a storm event. General guidance has been used to initially determine an approximate size and depth for this report. Sheets can be expected to be around 40' long. They will interface with existing bulkheads or sheet pile I walls depending on their location along the project. In most instances, new sheets will be driven directly against the existing walls (**Error! Reference source not found.**). Existing sheets will be left in place or removed, while the voids will be filled by some means of compacted fill or flowable fill. In some instances, sheets may be driven on the protected side of the wall (Figure B5- 1). Existing bulkheads would serve only as retaining structures and existing waterfront conditions would be allowed to remain.

To prevent failure in reverse head cases (opposite the direction of the flood load), sheets would be connected to new or existing anchorage systems. Depending on the capacity requirements of the different sheet pile wall sections and the condition/existence of the original anchorages, new anchorage systems may need to be installed to provide adequate support. Sheets may also be driven inland where anchorage would not be required.

Toe protection and armoring would be a key part of any sheet pile section. Toe protection would prevent wash out on the flood side of the wall in addition to providing a wave berm that would help to dissipate any wave forces before they impact the wall. Protected side armoring would provide protection against scour and failure due to overtopping.

To provide resistance to corrosion, sheets may be coated with a paint system or increased in size to provide sacrificial thickness. The paint system would require reapplication periodically to ensure proper adhesion and protection, particularly due to the fact that the walls are subjected to a brackish environment. Increasing the sheet pile section coupled with the application of a paint system should be considered in order to provide corrosion protection and section loss (strength reduction).

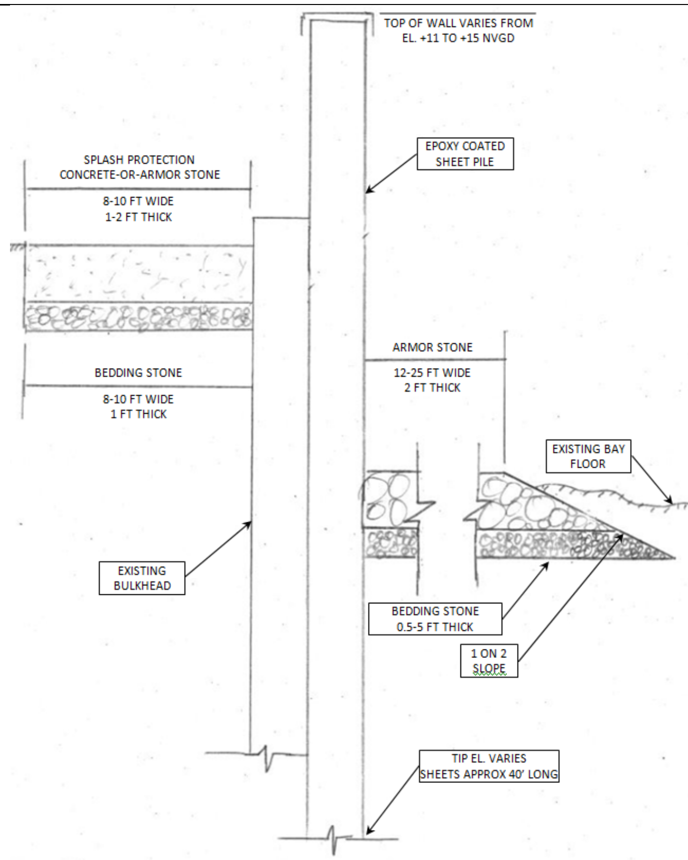

Figure B5- 1: Steel Sheetpile I-wall with Toe Protection and Armoring

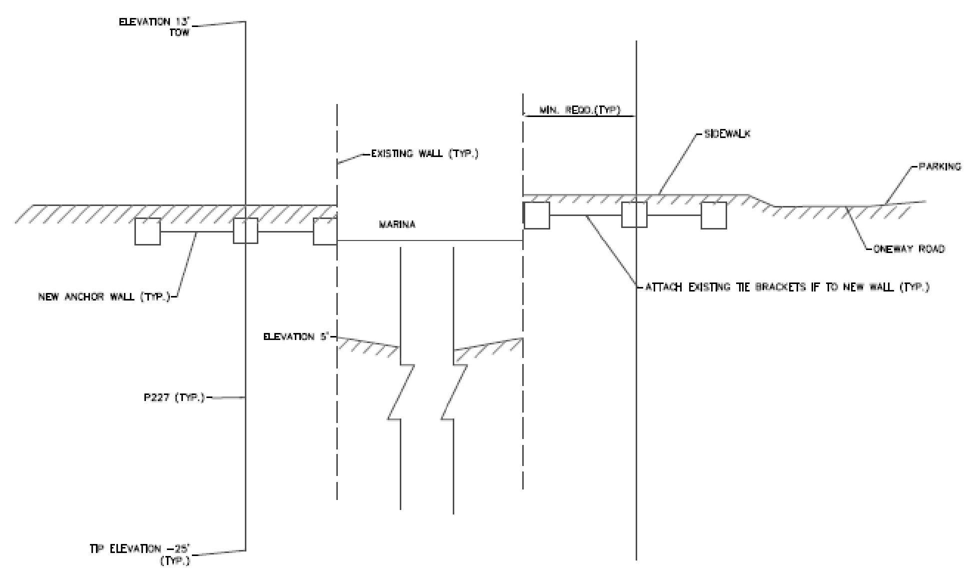

Figure B5- 2: Steel Sheetpile I-Wall with Anchorage (at Captains Cove)

2.1.2 Concrete Cap

In some sections of wall, a concrete cap is used as an option for strengthening and raising existing wall sections.

A concrete cap would be the most resilient and esthetically pleasing means of corrosion protection (Figure B5- 3). Most importantly, it can provide extra strength to an existing system. At the NJ State Bulkhead, concrete is fully integrated with the existing structure. A concrete "stem" would be poured over the existing sheet pile walls and then attached to a concrete base slab that is poured onto the protected side of the existing bulkhead. The new concrete would be positively attached to the existing sheet pile structure and would increase the height of the wall by utilizing the additional height of the concrete. During flood loading the existing sheet piling would mostly serve as a seepage cut off, however, some load may be transferred to the sheets. During the reversed head case, the existing sheet pile and sheet pile anchorage would serve as a retaining structure.

The feasibility of using a concrete cap is dependent on a variety of factors. The strength of the existing foundation is the key factor in the usability of this option. The capacity of the existing sheet pile structure to handle the extra weight of the wall in addition to the added flood loading from the increased height will affect the viability of using a concrete cap. Constructability should be considered when capping an existing sheet pile wall. Many of the existing walls/bulkheads in Highlands are located at the shoreline. Forming and pouring the flood side of this wall could pose potential complications and/or increase construction cost. Special support systems will have to be devised to support the flood side concrete while it cures.

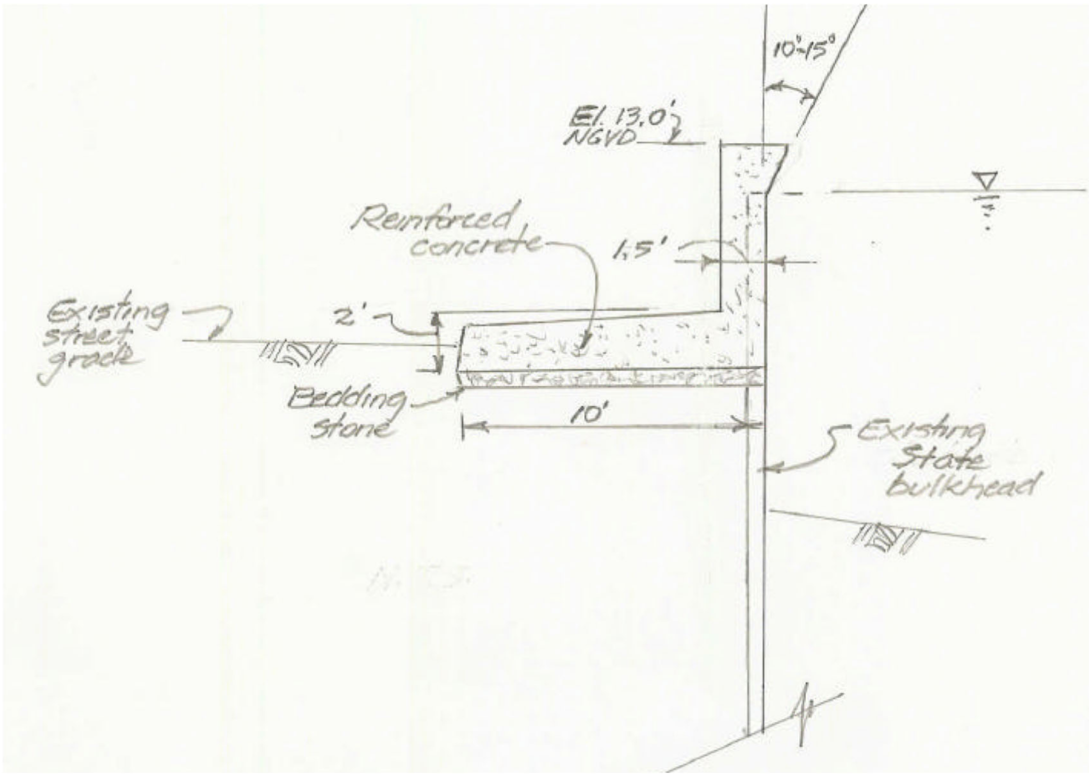

Figure B5- 3: State Bulkhead with Reinforced Concrete Cap

2.2 Offshore Closure Structure with Navigation Gate

This option would include a 4500' long breakwater embankment that extends from Highlands, across the bay to tie into Sandy Hook Spit. The breakwater would be built to elevation 12.4' NAVD88 and utilize impervious fill or a sheet pile core to provide coastal storm risk management. During tidal flood events, closure gates placed across waterways can be closed, and high flows pumped across the closure.

This feature would not only reduce the flooding risk of most of the Borough of Highlands, but also the risk of flooding to those upstream along the bay. At the location of the existing navigation channel, approximately 500 feet from the state bulkhead, a 135-foot wide navigation sector gate (Figure B5- 4) will be installed to allow for a 100-foot clear opening for navigation transit when the gate is in the open position. A sector gate allows for differential head on either side of the alignment, which would be useful for pre and post storm timeframes in which water has accumulated on the protected side of the gate, but has receded on the flood side. Prior to potential major storm events, the sector gate will be closed during a period of lower tide, sealing the inner basin and providing additional runoff storage leeward of the barrier. Along with the gate itself, a concrete monolith will have to be built into the existing channel in order to support the gate and provide a new access for vessels to pass through. The existing channel is around 20' deep. The gate depth would be sized to handle normal drainage from the bay and maximum required vessel draft. Sheet pile would be used to provide a link between the hardened concrete structure and the breakwater embankment. Consideration for the control of navigation through the structure would have to be considered.

2.3 Removable Fabricated Floodwall

A removable floodwall is a temporary structure that is erected prior to a flood event. Post-flooding, the barrier walls are stored offsite. It allows for vehicular and pedestrian access, unobstructed views and increased availability of land usage all the while providing coastal storm risk management when required. This alternative will be considered for the western half of Reach 4 only.

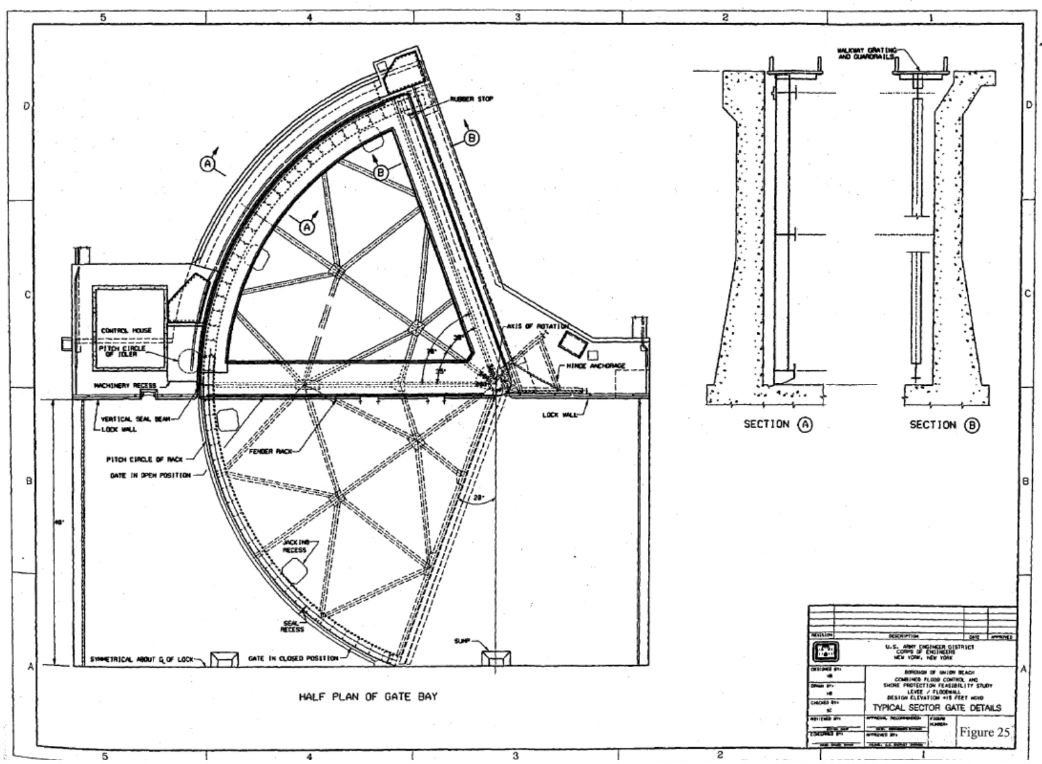

Figure B5- 4: Offshore Closure Sector Gate Example

A preliminary concept was created based on general requirements and information provided by producers of fabricated floodwall systems (Figure B5- 5). A metal sill plate and continuous concrete footing would be the only permanently installed component. The permanent structure would be set flush with the curb grade along the installation alignment. In advance of predicted high flood events, a trained crew will install vertical steel supports at 20-foot intervals with an intermediate support beam set between each parting support at 10-foot intervals. A base plank will be installed, and additional interlocking planks with watertight seals will then be stacked between each of the parting supports up to elevation +9.9’ NAVD88. The planks will be clamped down and squeezed tightly together to create a watertight seal. The height of the removable fabricated floodwall will be approximately 6 feet, with an erection time of approximately 3 hours utilizing three, 3-men crews. A portable ramp will be installed to allow for access over the floodwall after it is erected. The construction of a shed at a nearby public works facility will be required to store the floodwall supports and planks. A preliminary foundation design and stability analysis for the removable fabricated floodwall is based on the following preliminary analysis:

- Geotechnical borings along the proposed wall alignment are not yet available. They will be obtained during future phases of this project. However, since the location is near an existing heavily trafficked roadway and paved sidewalk and the total wall height is less than 6 feet, foundation conditions are anticipated to be satisfactory for the required bearing of the vertical cantilever supports. Therefore, pile support or diagonal bracing are not required. These assumptions will be confirmed in future phases of the project. This preliminary design assumes that the soil is sand with an angle of internal friction of 30 degrees and zero cohesion.

- Hydrodynamic wave forces and earthquake loading are neglected, as they are considered to be minimal.

- The design water level is at the top of wall – elevation +10 feet NAVD88. (This is the total 50-year storm surge elevation of +8.9 feet, plus a value of +1.1 feet for the hydrostatic wave force of small surface, wind generated inland waves).

- Frost depth is assumed at 38 inches below ground surface.

The foundation is a reinforced concrete slab, 4.5 feet thick immediately below the road ground surface (5 feet thick at the adjacent sidewalk) for a total 10-foot width. Therefore, for the entire length of 1,075 feet, 1,900 cubic yards of reinforced concrete will be required.

The wall stability was analyzed using the USACE’s EM-1110-2-2502 Retaining and Flood Walls Manual (1989). Significant overturning forces include the horizontal water pressure and the uplift pore pressure. Weights contributing to a resisting moment include the weight of water and soil over the base, and the weight of concrete. Since site specific soils information has not yet been collected, the preliminary design is conservative.

The hydraulic gradient between the upstream and downstream sides of the wall can cause a phenomenon called boiling. Boiling occurs when the hydraulic gradient exceeds the ratio of the submerged unit weight of soil divided by the density of water. This critical gradient is approximately equal to one for typical soils. The gradient along the shortest flow path in this preliminary design is 0.6, which is acceptable and predicts that boiling should not occur.

Required repaving of the surface on both sides of the wall after its installation will further lower the hydraulic gradient, helping to control seepage and improving wall stability. A sheet pile seepage cutoff could also be considered to help reduce the gradient. The final design should take these factors into account to insure stability during storm events and minimize final construction costs.

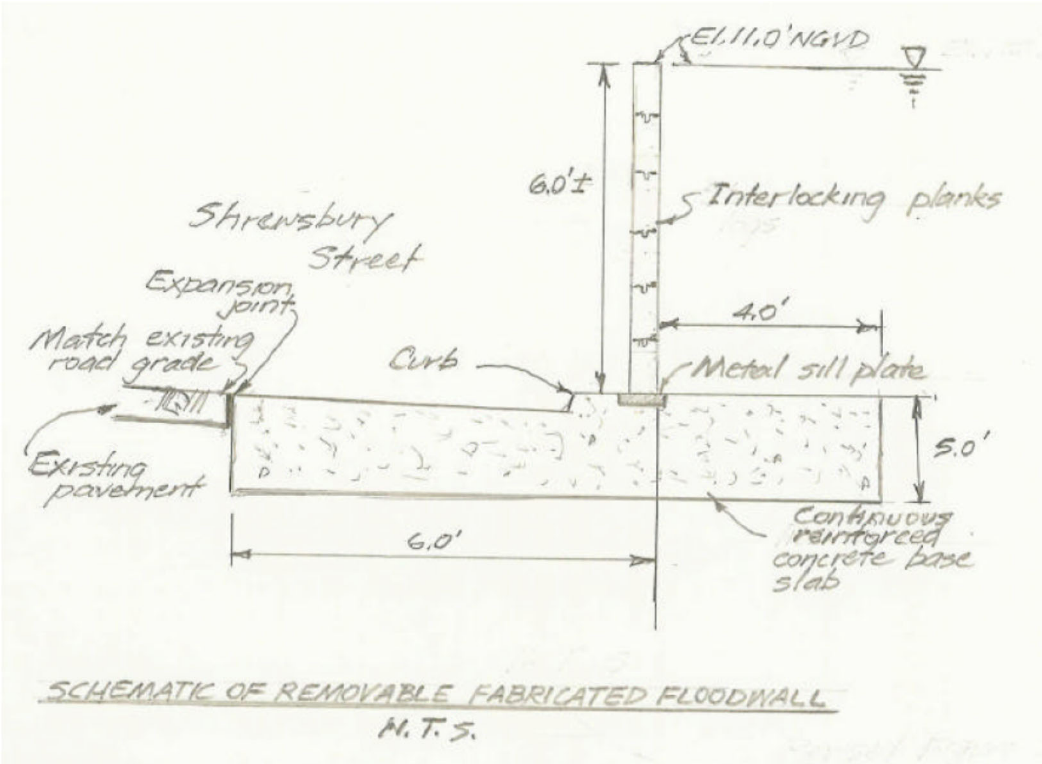

Figure B5- 5: Removeable Floodwall with Foundation Concept

2.4 Setback Concrete Floodwalls (I-type Floodwall)

Floodwalls are intended to provide risk reduction from coastal flooding to interior structures (Figure B5- 6). They follow the same principles as the modification of the existing bulkhead alignment. These structures may provide a cost effective means to prevent flooding of low-lying areas while reducing the impact on nearby structures and limit the land required for rights of way. They would most likely consist of a steel sheet pile integrated into a concrete reinforced stem. The sheet pile provides the foundation for the wall and is used to transfer the flood loads into the soil and to provide a seepage cut off. The concrete portion of the wall works to extend the protection to its final height and provides strength and corrosion resistance above grade. Concrete floodwalls are more esthetically pleasing than a typical sheet pile I wall. Concrete can also be more corrosion resistant and cost effective than similar lengths of standard sheeting.

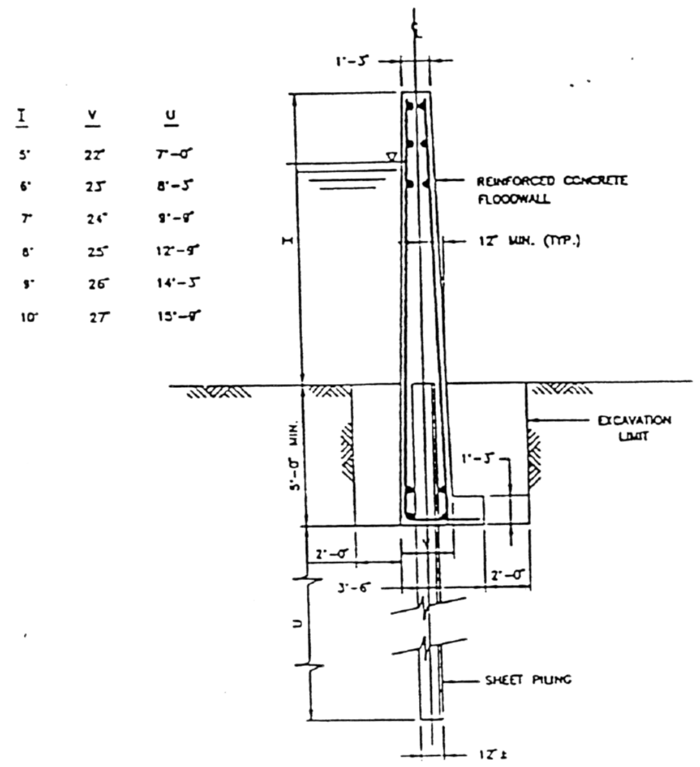

Figure B5- 6: Typical Reinforced Concrete I-Wall

2.5 Setback Concrete Floodwalls (T-type Floodwall)

Concrete T-walls follow the same principles as the modification of the existing bulkhead alignment. These structures are similar to Concrete I-walls, but they are more robust but increase impact on nearby structures and the land required for rights of way. T-walls have a flat or inclined base for distributing bearing pressures or pile forces to the foundation. They are less subject to wave overtopping and scour damage because the base extends on the protected side. They would most likely consist of a steel sheet pile integrated into a concrete reinforced T-shape. The sheet pile provides the foundation for the wall and is used to transfer the flood loads into the soil and to provide a seepage cut off. The concrete portion of the wall works to extend the protection to its final height and provides strength and corrosion resistance above grade. A typical reinforced concrete T-wall with piles is shown in Figure B5- 7.

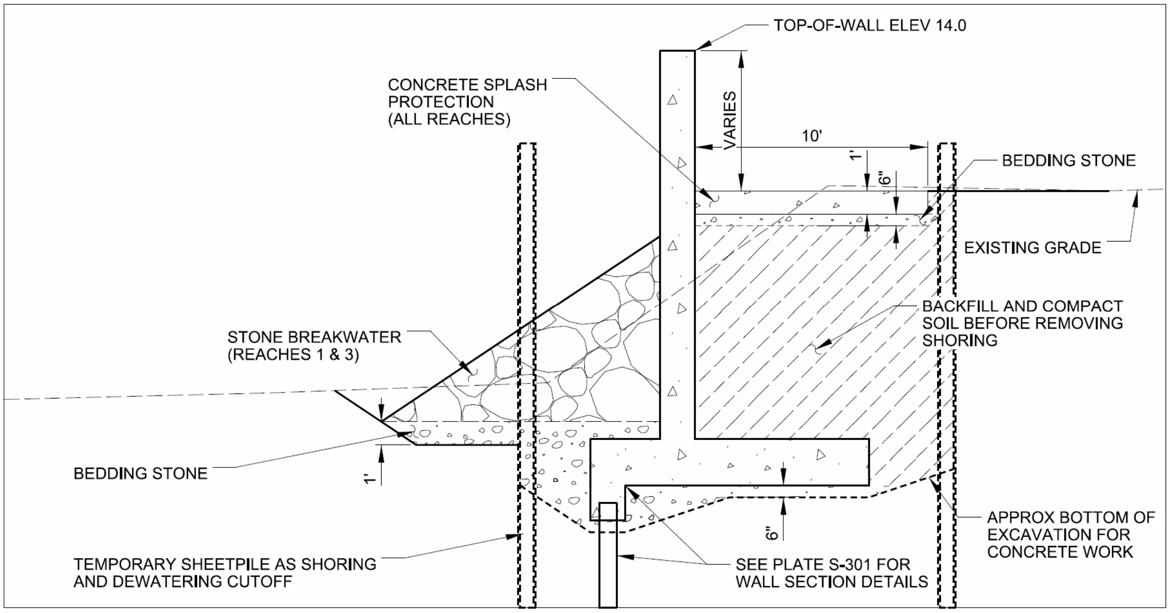

Figure B5- 7: Typical T-Wall Section with PIles

2.6 Closure Gate

To facilitate access to the flood side of a permanent floodwall system, vehicular and pedestrian closure gates will be included in some of the alternatives (Figure B5- 8). These openings are also used to facilitate operations at the existing marinas to allow loading and unloading of marine vessels. Closure gates require adjacent reinforced concrete abutments to seal against and adequate foundations to support flood loading and the self-weight of the structure. The gate abutments are also used to tie the gate structure to the main alignment. Closure gates are generally made up of welded steel shapes and plating that requires a paint coating to prevent corrosion. Operation of the gate can vary from simple hand tools to vehicle assisted closures.

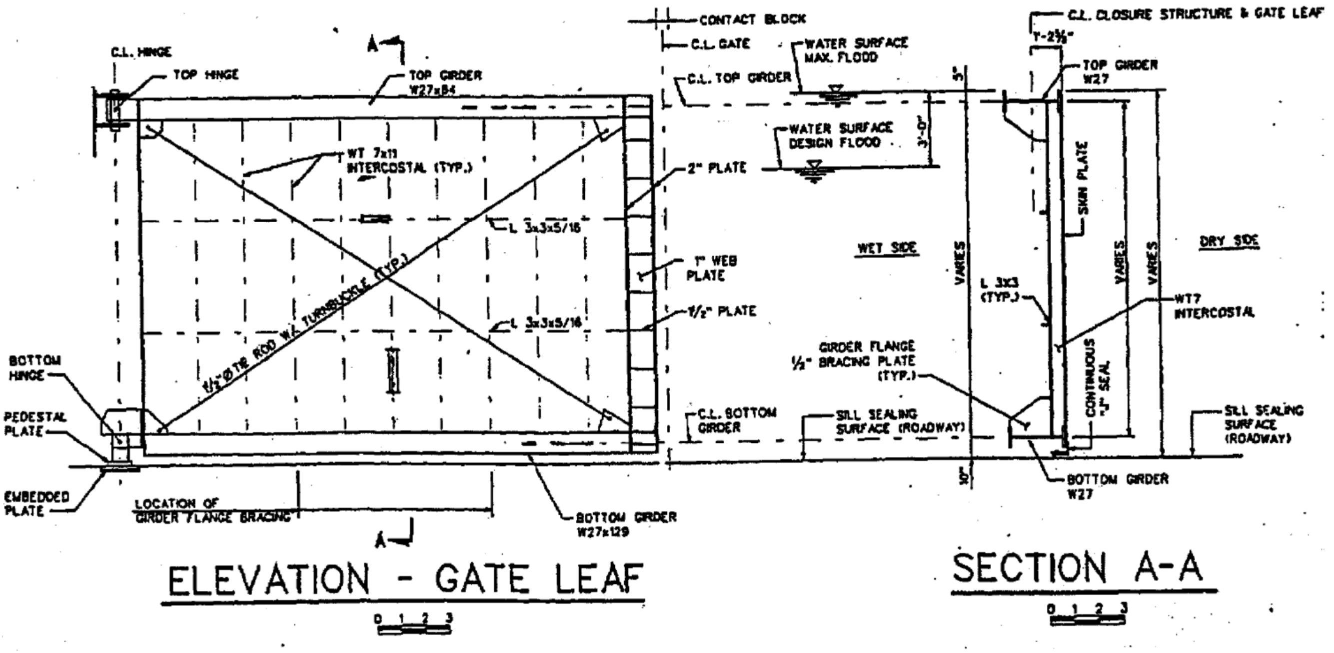

Figure B5- 8: Steel Closure Gate Example- Swing Gate

Chapter 3: Alternative Description

Structural alternatives were incorporated into each alternative to provide the reduced flood risk as required. All alternatives incorporated a raised sheet pile wall over some part of the project alignment except for Alternative 2. Removable floodwalls were incorporated into four alternatives to allow for increased land usage of a portion of Reach 4. Though the offshore closure prevents flood waters from even reaching most of the Borough of Highlands, the alternative still requires different types of coastal storm risk management to be construction, just over a smaller portion of the Highlands project area. Closure gates may or may not be used in Alternatives 5a-5e pending determination of the type of risk reduction that will be used at the eastern tie in at the end of Reach 4. The use of all structure types within each alternative are summarized in the table below.

Chapter 4: Optimization of Tentatively Selected Plan

The optimization of the TSP was performed on an array of alternatives. Elevations 11, 13, and 14 were identified as possible final levels of protection. Using criteria set forth in ETL 1110-2-575, it was determined that the majority of the alignment would require a "T" type wall for each alternative. Table B-2 of the ETL requires restrictions on the use of "I" type walls based on a combination of return period and foundation type, shown as **Error! Reference source not found.**, below.

Table B5- 1: Structure Types vs. Alternative

	Seawall/Bulkhead Mod.					
	Sheet Pile	Concrete Cap	Offshore Closure	Removable Floodwall	Closure Gate	Setback I-Wall
Alternative 1						
Alternative 2						
Alternative 3						
Alternative 4						
Alternative 5						
Alternative 5a					*	
Alternative 5b					*	*
Alternative 5c					*	*
Alternative 5d					*	*
Alternative 5e					*	*

Table B5- 2: Foundation Characteristics

Annual Chance of Exceedance	Foundation Type			
	Sand $\varphi \geq 32.5$, $D_r = 0.50$	Soft Clay $S_u \leq 300$ psf (14.4 kPa)	Stiff Clay $S_u \geq 1{,}500$ psf (71.8 kPa)	I-wall on Levee
1% and above	7 (2.1)	5 (1.5)	8 (2.4)	4 (1.2)
0.2%	9 (2.7)	7 (2.1)	12 (3.7)	4 (1.2)
0.1% and below	11 (3.4)	8 (2.4)	15 (4.6)	4 (1.2)

All study elevations were below the 1/100 Annual Chance of Exceedance, therefore this level was utilized for the purpose of this study as it is the closest range to the return periods of this study. Preliminary geotechnical investigations determined that the general characteristic of the foundation soil in this Highlands area was sand. Based on these two project characteristics, 7 feet was the maximum allowed height of an I-wall before a more robust T-wall is required.

Using the 7 foot limitation and comparing it to the existing topography along the future project alignment, lengths and stickup heights of the new T-Wall sections were obtained. Wall heights between 7 and 18.5 feet would be required. Using this range, 3 different cross sections of walls were designed. One cross section was created for walls between 7 and 9 feet, one between 9 and 13 feet and on greater than 13 feet. Foundation type and anticipated hydrostatic loadings were incorporated to the design to obtain a general footing width and thickness along with a wall stem thickness. Preliminary reinforcement was also incorporated into each wall section to ensure constructability. A sheetpile seepage cutoff was utilized on the flood side of the wall foundation was used to limit seepage and uplift. The depth of the cutoff was determined by preliminary geotechnical analysis of the local soil layers. A more in depth study will be needed during final design to potentially reduce the depth of the cutoff and to further define the soil properties for the foundation.

Chapter 5: Summary

Each structural flood risk reduction method is a viable option for this project. Estimates have been made as to the size, type and location of each structure based on preliminary engineering analysis of known conditions and requirements of the project site. Considerations during final design should be expanded to include an in depth foundation analysis based on site specific conditions, multiple load combinations including wind, wave and boat loadings, and further coordination with other disciplines to ensure items such as seepage and access are taken into account for each unique wall section. The preliminary data used to create the alternatives in this report has been used to generate basic costs for the materials, construction, and maintenance of the structures themselves. In addition, the requirements of the type of structures applied to a specific reach can assist in determining initial estimates for construction limits, level of difficulty of the construction, and right of way requirements. Once implemented, any final alternative that utilizes these structural methods will achieve the goal of lowering the risk of losses due flooding to the borough of Highlands New Jersey.