Boston Coastal Storm Risk Management Study

Draft Integrated Feasibility Report and

Programmatic Environmental Assessment

Photos: Top and Middle- 2018 Nor'easter courtesy of businessinsider.com
Bottom- Flooding beneath Evelyn Moakley Bridge. Courtesy of Alison Brizius, December 2022

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USACE New England District | City of Boston

US Army Corps of Engineers

Contents

1.0 INTRODUCTION

This study's structural engineering scope focuses on evaluating different types of flood barriers and assessing their feasibility in protecting the City of Boston from hurricane-induced storm surges.

The flood barrier's route and top elevation were determined in collaboration with the City of Boston and other stakeholders. It follows the city's perimeter along the waterfront in four primary neighborhoods: Charlestown, East Boston, Downtown, and Dorchester. The design must accommodate pedestrian and vehicular movement, stormwater management, existing utilities, and the Waterfront access.

The flood barrier's top elevation varies by location along particular alignments, including El. 14 and El. 15 ft-NAVD88. This design include variance due to differing wave high by location.

Several flood barrier types were evaluated, including Earth Berms (Levees), I-Walls, T-Walls, Combo Walls, Swing Gates, and Stop Logs at pedestrian and vehicle crossings. Each option has distinct requirements, limitations, and footprint considerations, all of which are explored in this report.

For this feasibility study, the structural design effort was limited to only determining the basic requirements and to provide sufficient structural information to determine feasibility costs. The structural design will be further developed during Preconstruction Engineering and Design (PED) Phase.

2.0 REFERENCES

Structural design in the Corps of Engineers is governed by Engineering Regulations (ER's), Engineering Manuals (EM's), Engineering Technical Letters (ETL's), and Engineering Circulars (EC's). These documents are available online at usace.army.mil under the Library and Publications tabs. The following criteria documents are pertinent to the City of Boston flood barrier:

EM 1110-2-1901	Seepage Analysis and Control for Dams 9/30/1986
EM 1110-2-2000	Standard Practice for Concrete for Civil Works Structures 3/31/2001
EM 1110-2-2100	Stability Analysis of Concrete Structures 12/1/2005
EM 1110-2-2102	Waterstops and Other Preformed Joint Materials for Civil Works Structures 9/30/1995
EM 1110-2-2104	Strength Design for Reinforced Concrete Hydraulic Structures 1/08/2025
EM 1110-2-2502	Retaining and Flood Walls 8/01/2022
EM 1110-2-2503	Design of Sheet Pile Cellular Structures, Cofferdams, & Retaining Structures 6/11/1990
EM 1110-2-2504	Design of Sheet Pile Walls 3/31/1994
EM 1110-2-2906	Design of Pile Foundations 1/15/1991
ER 1110-2-1806	Earthquake Design and Evaluation for Civil Works Projects 5/29/2024
EM 1110-2-2107	Design of Hydraulic Steel Structures 8/01/2022

UFC 3-301-01	Structural Engineering C3 2/03/2025
IBC 2024	International Building Code
ASCE 7-22	Minimum Design Loads for Buildings and Other Structures

Note: Current editions of all criteria documents will be used during PED phase. In the event of discrepancy between UFC 3-301-01 and IBC 2024 or ASCE 7-22 load criteria, the higher load will govern Structural engineering during PED phase.

3.0 LOAD CASES

The load cases considered for this study were in accordance with Coastal Flood Wall requirements in EM 1110-2-2502. A preliminary structural stability analysis was performed using Microsoft Excel to determine forces on the structures and reactions on the pile foundation. Detailed structural design of the walls will be accomplished during PED phase.

- C1: Surge Still Water Loading
- C2a: Nonbreaking Wave Loading
- C2b: Breaking Wave Loading
- C2c: Broken Wave Loading
- C3: Earthquake Loading
- C4: Construction Short-Duration Loading
- C5: Wind Loading
- C6: Debris/Boat/Barge Impact Loading

4.0 FOUNDATIONS

Due to the existence of thick organic layers in Boston soil, the typical floodwalls are planned to use foundation piles embedded in or below the Boston Blue Clay stratum. This strata typically ranges from elevation EL -55 NAVD 88 to El -75 NAVD 88, depending on the neighborhood.

In some limited locations, shallow foundations have been identified for floodwalls, typically due to conflicting utilities. In this case, foundation improvements will be required to prevent consolidation from the organics and reduce seepage beneath the floodwall.

5.0 EARTH BERM (LEVEE)

See Civil and Geotech Appendices for additional information regarding earth berms or levees.

6.0 I – WALL

I-walls are generally deemed unsuitable for flood wall construction. These barriers consist of driven sheet pile walls topped with concrete. While their compact footprint makes them ideal for areas with limited space, their poor performance during Hurricane Katrina led to updates in USACE design criteria, restricting new I-wall heights to a maximum of 4 feet above the current finish grade.

I-walls are not utilized for the Boston CSRM.

1.0 L– WALL

L-walls consist of a stem, short foundation base, and a cutoff sheet pile. Generally, L-walls cannot be used in areas with high hydrostatic pressure or high wave crests. An L-wall is only utilized in one alternative for the Boston CSRM, the Chelsea Street closure alternative for the Charlestown alignment. Due to the short wall height of < 3 feet and the plethora of utilities in the area, the L-wall was deemed more economical than a T-wall.

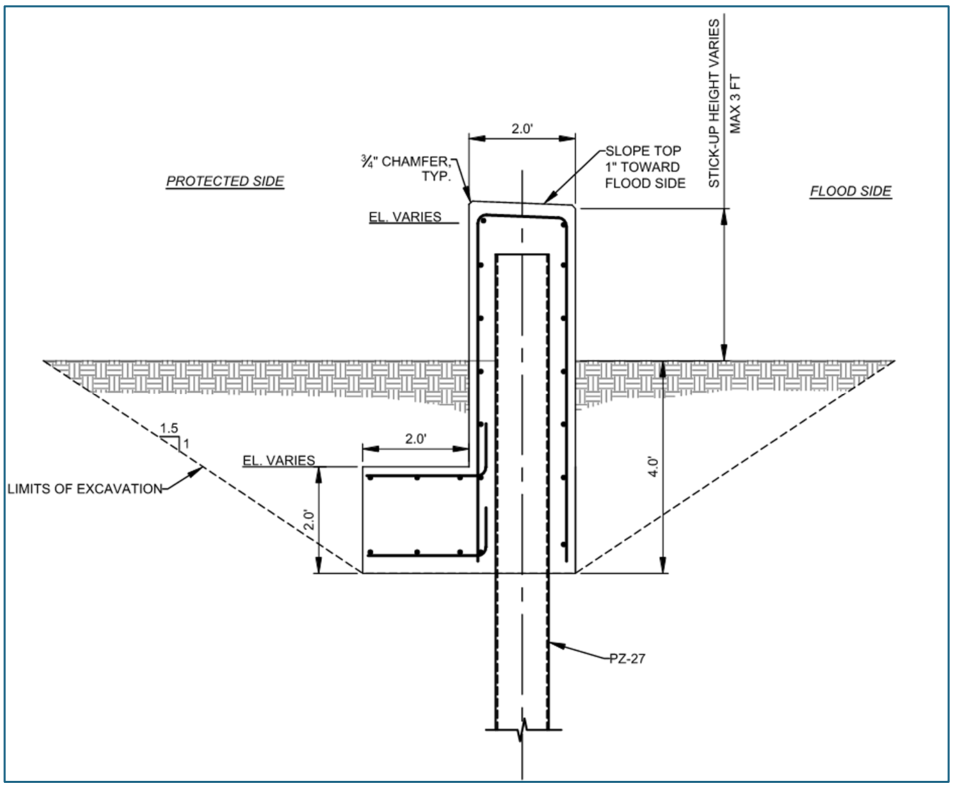


Figure 1 – Proposed L-Wall

The proposed landside L-wall was designed for only a 3 foot height. A sheet pile cutoff is included below the wall to prevent flood water from seeping beneath the structure. Horizontal and overturning forces from the horizontal floodwater and waves is resisted by the sheet pile and the concrete toe of the headwall.

2.0 T – WALL

T-walls will be used in areas where the barrier can be built on land. These structures feature a reinforced concrete stem and foundation, along with a sheet pile cutoff wall and vertical and batter piles. The accompanying sketch illustrates steel sheet piles and concrete-filled pipe piles. Batter piles will be utilized to limit movement of the wall when loaded, ensuring that differential displacement does not tear the waterstop.

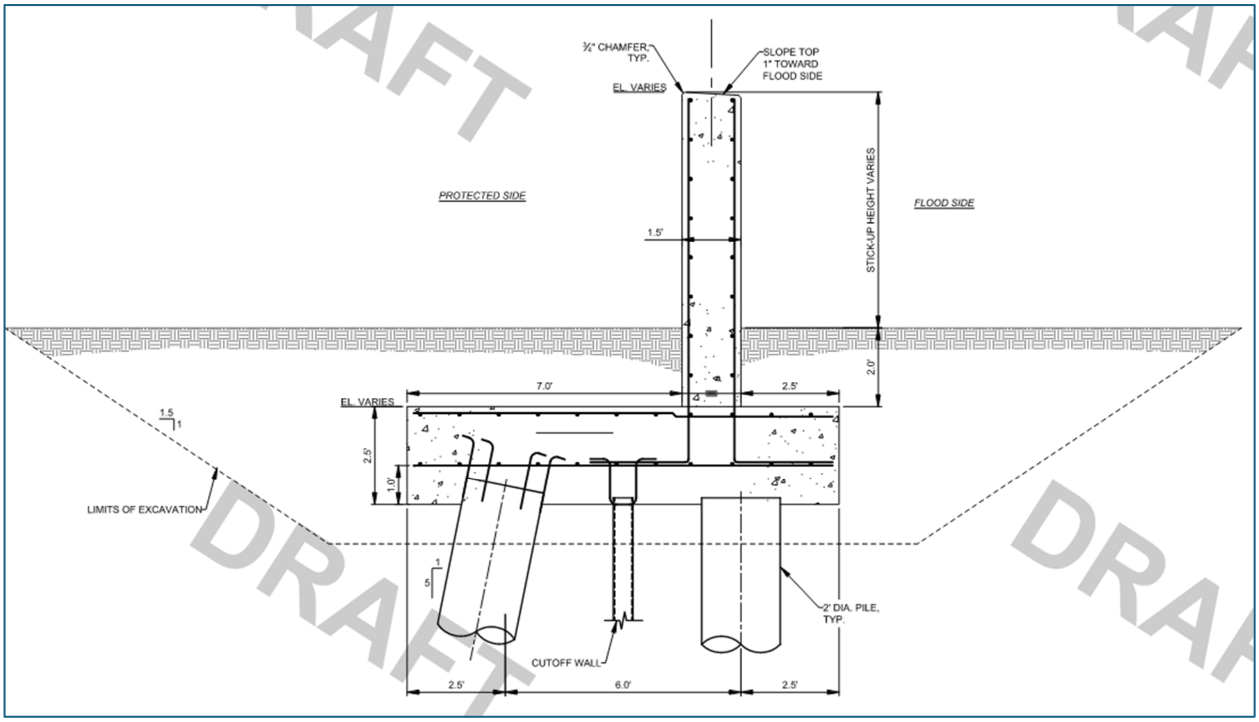


Figure 2 – Proposed Landside T-Wall

The proposed landside T-wall was designed for three general heights – 3 feet, 6 feet, and 9 feet. A sheet pile cutoff is included below the wall to prevent flood water from seeping beneath the structure. Pile foundations are included for two reasons – resisting vertical settlement due to soft soils beneath the structure and resisting the horizontal forces of floodwater and waves.

3.0 WATERSIDE FLOODWALLS

In some instances, there is insufficient land to build the T-wall. In this situation, a waterside solution was developed, to be built in the sea. Two variants of the waterside solution were developed.

The first is an L-shaped concrete floodwall that will function like a pier. Similar to the T-wall solution, this wall makes use of batter piles to limit movement when loaded. The L-shaped floodwall also utilizes a combo-wall, where a sheet pile runs between pipe piles to provide structural support as well as hydraulic cutoff. To prevent stagnant water from sitting behind the wall, lightweight backfill will be placed between the sheet pile cutoff and the land or structure on the protected side, such as the granite block walls common to the Boston waterfront.

The second is a concrete seawall, utilizing precast concrete panels braced with reinforced concrete piles. This seawall has limited use for areas requiring 3 ft or less of protection. However, compared to the T-wall, the concrete panel seawall has a significantly smaller footprint.

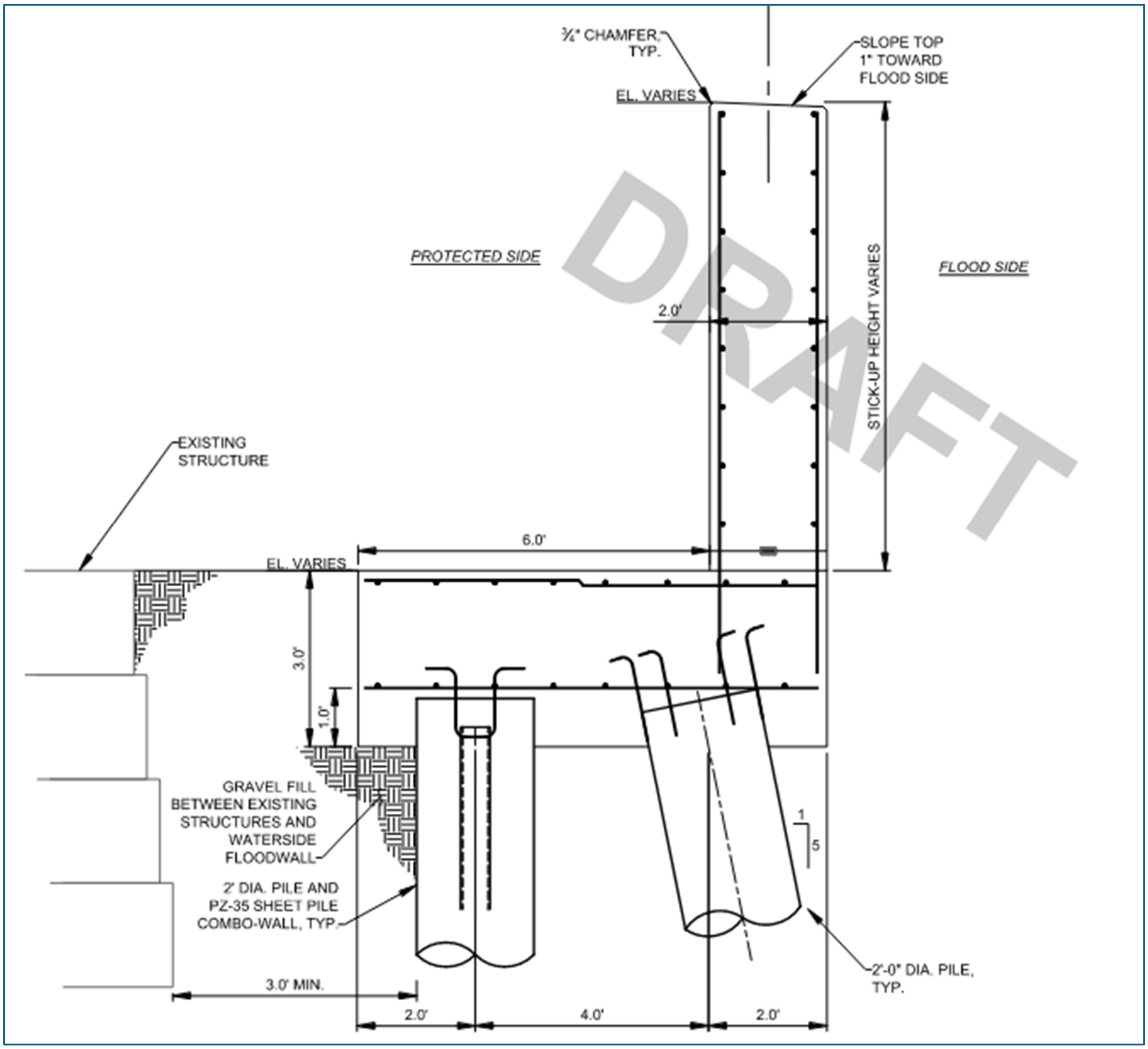


Figure 3 – Proposed Waterside Wall with Combo-wall and Batter Pile

The proposed waterside wall with combo-wall and was designed for three general heights – 3 feet, 6 feet, and 9 feet. A sheet pile cutoff is interlocked between the vertical piles to prevent flood water from seeping beneath the structure. Pile foundations are included for two reasons – resisting vertical settlement due to soft soils beneath the structure and resisting the horizontal forces of floodwater and waves. Gravel is backfilled between any existing structures and the combo-wall so that a void does not remain.

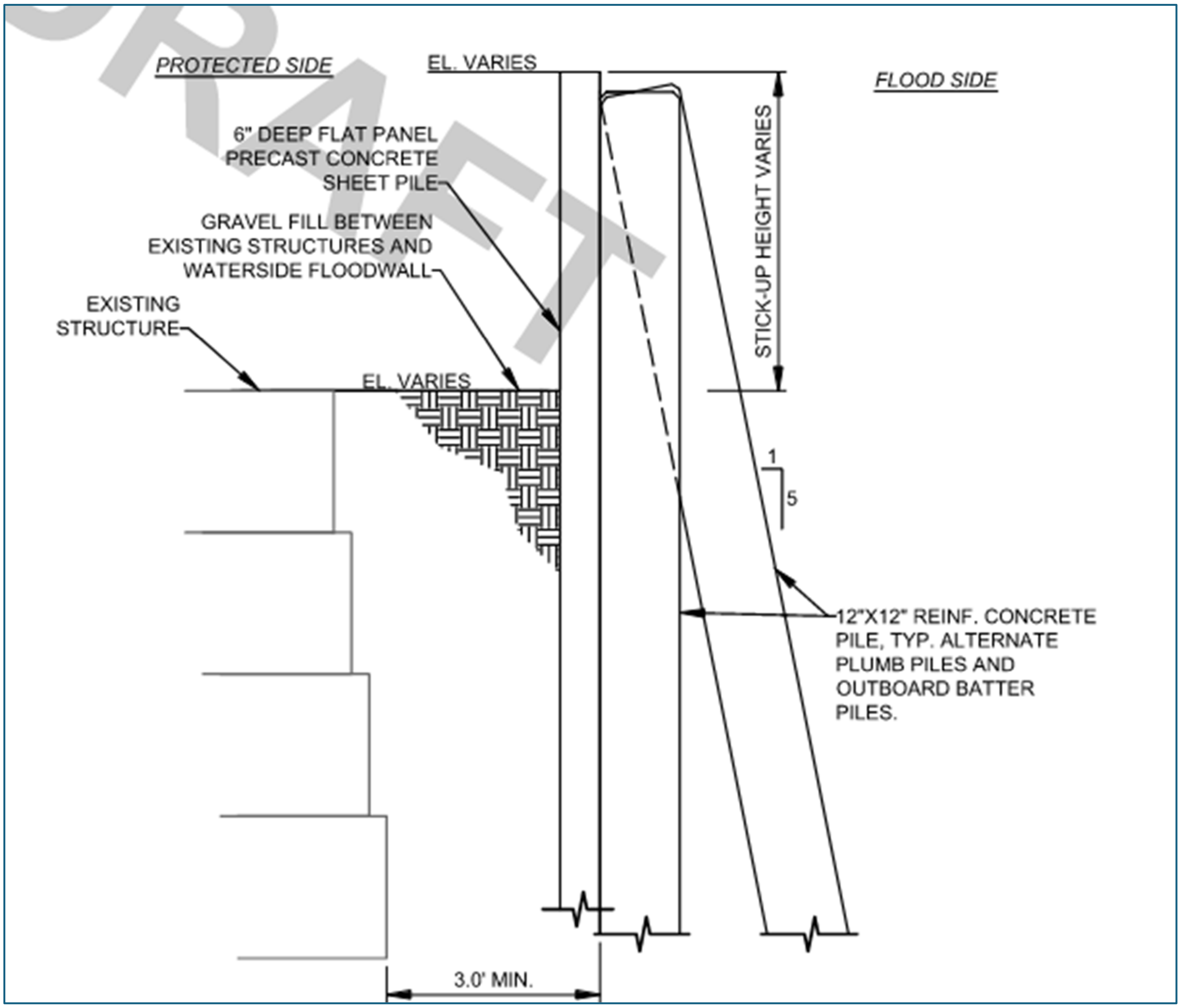


Figure 4 – Proposed Waterside Wall with Precast Concrete Panels

The proposed waterside wall with precast concrete panels was designed for 3 foot only. Concrete piles are installed as the primary structural element of the wall, which will hold the precast panels in place. Precast concrete panels are inserted behind the piles along with the gravel backfill between the panels and existing structures.

4.0 GATES

A preliminary structural analysis and design were conducted for the gates, which will vary significantly in size—from large gates spanning roadways to smaller gates for pedestrian access. To ensure the barrier remains watertight during storm events, multiple types of gates are needed throughout the study area. These gates can be categorized into four main groups: Stop Logs, Swing Gates, Roller Gates, and Mitre Gates. The specific gate design depends on its installation location. Detailed information on each category is provided below. Generally, all gates will remain open under normal conditions and will only be closed when necessary due to a coastal storm event.

4.1 STOP LOGS

Stop log closures are a modular type of barrier used to control or block water flow. Individual horizontally placed stop logs are placed into vertical guide channels embedded into concrete floodwall or abutments. During a flood event, these logs are stacked one on top of another until the required protection height is achieved. For wider openings that exceed the structural spanning capability of a single log, removable intermediate support posts are installed across the gap, allowing multiple adjacent sets of stop logs to be deployed side-by-side.

Compressible seals integrated along the bottom and sides of each log ensure a watertight barrier, with the hydrostatic pressure from the wet side actively compressing the seals against the guide channels. Once seated within their reinforced guides, the engineered logs provide the necessary structural integrity to withstand hydraulic forces without the need for additional dry-side bracing. However, unlike simpler hinged barriers, stop log systems almost always require powered lifting equipment—such as overhead cranes, mobile hoists, or specialized lifting beams—to safely transport, lower, and remove the heavy logs, making their deployment a more involved logistical operation.

Figure 5 – Stop Log Example (Photo Courtesy of East Hartford, CT)

4.2 SWING GATES

Swing gates are the most straightforward and easiest type to install and operate. A large, reinforced metal gate is secured to the wall with hinges on one side. To close, it simply swings into position and locks onto the opposite side of the opening. For wider openings, two gates can be installed—one on each side—swinging together at the center, where a removable support post provides stability.

Compressible seals along the bottom and sides ensure a watertight barrier. Additional removable supports may be installed on the dry side to enhance structural integrity against hydraulic forces from the wet side. Typically, swing gates do not require powered equipment and can be operated manually with sufficient personnel. However, larger gates may necessitate heavy lifting equipment for opening, closing, and installing extra supports.

An example photo of a single-span swing gate from New Orleans, LA is shown in Figure 5.6.2 below. The primary drawbacks of swing gates include the significant clearance needed for closure and exposure to the elements when not in use. Nevertheless, due to their ease of maintenance and cost-effectiveness, swing gates will be prioritized and installed in all locations where adequate clearance is available.

Figure 6: Swing Gate Example (Photo by USACE Charleston District)

4.3 SLIDE GATES

Slide gates are straightforward and relatively easy to install. A large, reinforced metal gate moves along a track, sliding into place from one or both sides of the opening. When closed, compressible seals along the bottom and sides create a watertight barrier by pressing against the wall or adjoining gate.

Depending on its dimensions, additional bracing can be installed on the dry side to help withstand water pressure. One advantage of slide gates is that they do not require the same clearance as swing gates. Additionally, they can potentially be stored within the wall itself, protecting the gate, seals, and moving components from exposure when not in use.

See examples of a slide gate integrated into a floodwall system in Norfolk, VA in Figures 5.6.3 and 5.6.4 below. Depending on size, slide gates may include a manual cranking mechanism, though many require a motorized system for opening and closing. Due to their simple design and ease of operation, slide gates will be prioritized in locations where swing gates cannot function properly due to space constraints.

Figure 7: Slide Gate Example (Photo courtesy of USACE Norfolk District)

Figure 8: Slide Gate Example (Photo courtesy of USACE Norfolk District)

4.4 MITER GATES

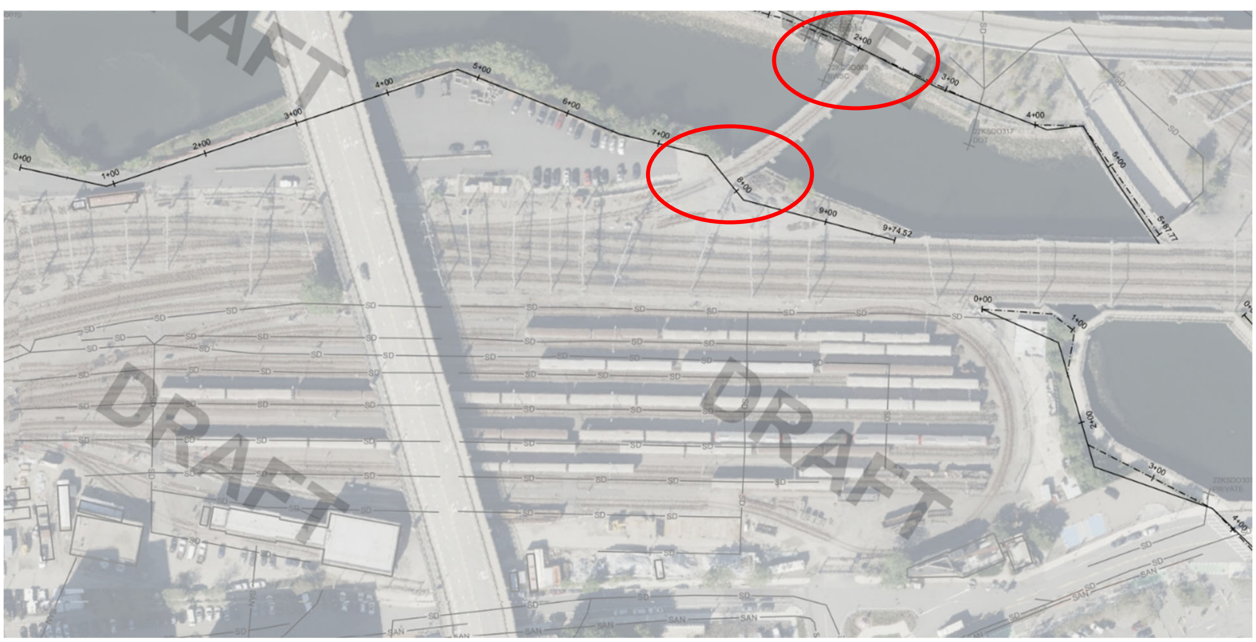
Miter gates are a self-reinforcing type of closure, designed to use water pressure for stability. The structure consists of two large, reinforced metal gate leaves, each secured to opposing walls with heavy-duty hinges. To close, the leaves swing together and meet at an angle in the center of the opening, forming a "V" shape pointing toward the high-water side. Because the two gates physically brace against one another at this center meeting point, they can span significantly wider openings without the need for any removable center support posts.

Compressible seals along the bottom sill, the side hinges, and the vertical center seam ensure a watertight barrier. The angled geometry is structurally critical: hydraulic forces from the wet side push against the gates, they are compressed more tightly together, transferring the massive hydrostatic load directly into the reinforced concrete abutments without needing additional dry-side bracing. Because of their sheer size, weight, and the precise alignment required at the miter seam, these gates are generally not operated manually and require permanently installed electromechanical or hydraulic machinery for smooth opening and closing operations.

Miter gates are typically used in marine applications, such as locks and canals. It is typically cost prohibitive for land use, due to the large abutments. For the Boston CSRM project, miter gates have primarily been considered for areas crossing water.

4.5 RAILROAD GATES FOR MBTA

Early coordination with the railroad (MBTA) is essential when planning and designing crossings, as general guidelines like AREMA may not fully address site-specific operational and safety requirements. Design considerations include construction phasing, track downtime, foundation placement, and clearance within railroad infrastructure, as well as factors like robotic train operations and gas lines for switch heaters. Crossings should typically be perpendicular to the tracks, with sill widths fitting within the clear distance between railroad ties. Roadway crossings should be at grade and accommodate emergency access, with swing or roller gates preferred for evacuation routes. Designers must also consider crash-tested barriers, highway speeds, drainage, and grading to ensure long-term safety and functionality.



4.6 STORM DRAINAGE CHECK VALVES

There are multiple locations where the wall will intersect existing underground storm drainage lines. To prevent water from flowing back through these lines, a check valve will be installed in the underground stormwater system where the pipes pass beneath the wall. Check valves allow water to flow in only one direction, enabling stormwater to exit the system normally while preventing reverse flow once outlet water levels reach a point where backflow could occur.

These valves will then reopen automatically when outlet water levels drop, allowing water to drain from the interior of the wall. During the PED phase, the drainage system will be assessed to determine the most suitable type and placement of check valves. When feasible, a flap gate-style check valve may be preferable at the stormwater outfall rather than directly at the wall's crossing point over the drainage line.

Figure 9: Example of Flap Gate Style Check Valve (Photo courtesy of USACE Norfolk District)

4.6.1 PORTAL CLOSURE STRUCTURES

4.6.2 OTHER VEHICLE GATES

There are various alternative gate options, including pop-up gates, flood-sensing automatic gates, and modular section gates. Generally, these gates tend to be more costly, require more maintenance, and incorporate additional mechanical and electrical components. Their use will be evaluated individually during the Preconstruction, Engineering, and Design (PED) phase, but only if swing and slide gates are not viable solutions. However, these alternatives are expected to be used sparingly, if at all.

4.7 GATE PREVENTATIVE MAINTENANCE

Regular maintenance is essential to ensure the proper functioning of all gates. Vehicle and pedestrian gates require relatively straightforward upkeep, primarily involving periodic seal inspections and replacements as needed. Additionally, slides and tracks should be cleaned and lubricated several times a year to maintain optimal performance. Gates with motorized operation will require standard maintenance, including lubrication. With routine care, vehicle and pedestrian gates are expected to remain operational for the duration of the project, provided components like seals are replaced when necessary.

Storm gates will require similar maintenance to pedestrian gates, with the added necessity of routinely clearing seats and seals of vegetation, algae, and debris to maintain an effective seal. Due to their exposure to environmental conditions, including saltwater, it is anticipated that at least one full gate replacement will be necessary over the project's lifespan, though supporting structures, such as concrete casings, will remain intact.

5.0 GATE CLOSURES

The procedure for closing these gates will be finalized during the PED phase and outlined in an Operation and Maintenance Plan. Generally, all gates will remain open and will only be closed in response to a coastal storm flooding event. The timing for closing gates will depend on water levels and the need to balance operational and evacuation requirements, which may result in different threshold levels across various areas of the city.

Storm gates will be closed when the National Weather Service predicts a significant storm surge for the region, as detailed in the City of Boston’s overall emergency management plan. To optimize water storage capacity, storm gates should be shut during the final low tide cycle before the anticipated storm impact. However, if this cycle occurs too close to the storm’s arrival, making safe closure unfeasible (as defined in the City’s emergency management plan), the gates will be closed during the preceding low tide cycle. Given that low tide occurs approximately every 12 hours, gates should not remain closed for more than 24 hours before storm impacts. Currently, the designated elevation for closures varies by neighborhood. See the Civil Engineering appendix for details.

Terminology

Major Flooding: *Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations (NOAA NWS).*

6.0 UTILITY CROSSINGS

An approach was evaluated to ensure the seamless integration of the sheet pile cutoff wall at utility crossings. Since utilities must remain operational during flood wall construction, their precise locations need to be identified before excavation or pile driving begins. The continuity of the sheet pile structure is critical for its effectiveness as a cutoff wall, presenting a significant challenge. To address this, the sheet pile is omitted at utility crossings, and jet grouting is used to form a cutoff wall panel around the utility, as illustrated below.

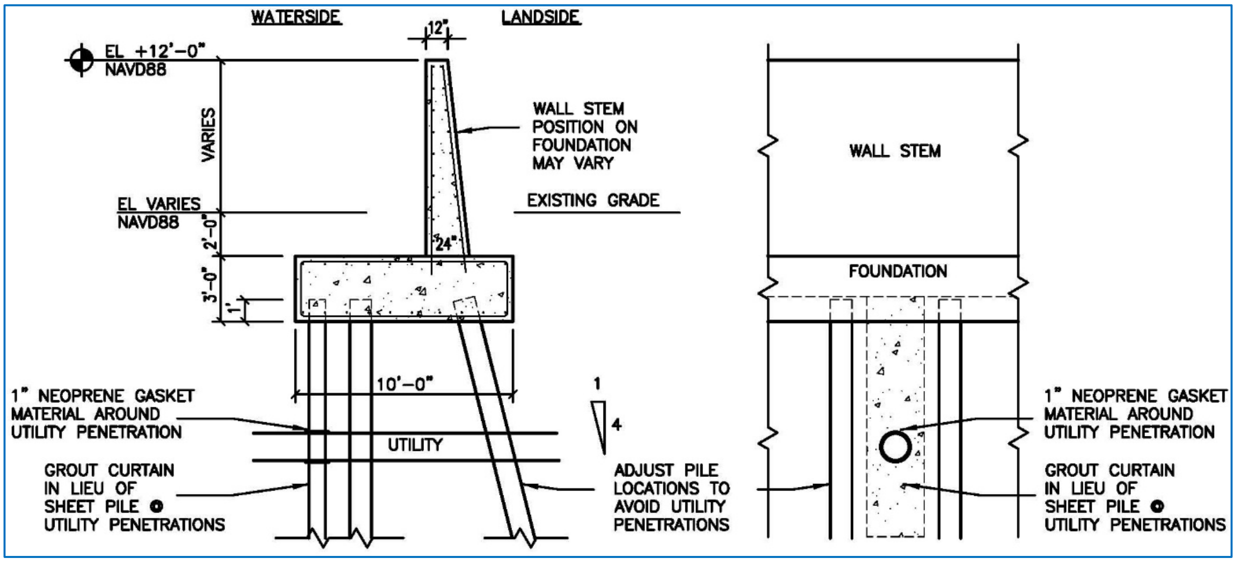


Figure 10: Example Utility Cross for Existing Utility

7.0 BRIDGE CLEARANCES

Special cases have been evaluated where the flood barrier will need to pass beneath existing bridges. In areas with limited vertical clearance, full-height piles cannot be installed. Instead, piles must be placed in sections and joined using welded or bolted connections. Micropiles are a viable alternative, as they are typically segmented and assembled using threaded connections. Below are specific locations where vertical clearance constraints pose a challenge.

- Seaport Blvd/World Trade Center (South Boston)
- Barry Playground (Charlestown)
- Little Mystic (Charlestown)
- Fort Point Channel (South Boston)
- Neponset Trail (Dorchester)

8.0 FUTURE DETAILING AND RESILIENCY

Given the challenges posed by sea level rise and the harsh marine environment where the barrier will be built, proactive measures are necessary to ensure adaptability, long-term performance, reduced maintenance, and durability. The following considerations have been incorporated and will continue to be refined during the Preliminary Engineering and Design (PED) phase:

- Oversized substructure and superstructure to allow for future height increases
- Use of durable materials like stainless steel to enhance longevity and maintainability
- Strategic gate storage by positioning it nearby for easy access

- Efficient gate deployment to ensure reliability and functionality

9.0 INCREASING BARRIER HEIGHT

The T-Wall and Combo Wall incorporate both vertical and battered piles, which will be driven into the Boston Blue Clay stratum. The load capacity of piles driven into the Blue Clay significantly increases with each additional foot of penetration. Structural analysis has factored in the necessary pile embedment to support a flood barrier with an additional three feet of height, ensuring feasibility.

During the PED phase, concrete reinforcement for all wall types should be designed to withstand forces associated with potential future height increases. Any future raising of the flood barrier should require only dowelling into the top of the structure to integrate additional rebar and extend the wall stem.

10.0 CORROSION PREVENTION

This project will be developed along the perimeter of the Boston Harbor, an area exposed to seawater and salt marshes, creating a highly corrosive environment. To minimize maintenance needs and enhance durability, effective corrosion prevention strategies should be implemented. Recommended measures include:

- Noncorrosive rebar, such as galvanized, epoxy-coated, or FRP composite
- Noncorrosive sheet pile, including prestressed concrete, vinyl, or FRP composite
- Corrosion-inhibiting admixtures for concrete
- Stainless steel for railings and hardware

11.0 INTERIOR DRAINAGE

Interior drainage design, including cistern, pipe, and pump sizing is being performed by Boston Water & Sewer and is not part of this USACE study.

12.0 NON-STRUCTURAL

For this feasibility study, only one structure was identified and detailed for non-structural solutions. The Charlestown Community Center in Charlestown was proposed to have floodproof windows and doors, and waterproofing membrane installed in front of the concrete and masonry on the building’s exterior. Additional waterproofing treatment would be performed on the interior slaps on the structure.

During PED, additional structures may be identified as requiring non-structural solutions.

ATTACHMENTS