Flood Defense Alignment Studies

Financial District and Seaport Climate Resilience Master Plan

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1. Overview & Objectives

To protect the Financial District and Seaport neighborhoods from the impacts of climate change, the City is prioritizing flood defense infrastructure that responds to both future tidal flooding and coastal storms. The unique conditions of this area create a complex environment for constructing this infrastructure. Larger waves than nearby areas due to its location in New York Harbor compounded with low-lying topography and unique above- and below-ground conditions require the City to take a bold approach to adapt this area to climate change. This appendix is intended to supplement the *Financial District and Seaport Climate Resilience Master Plan* Chapter 5, Section 1: A Resilient 21st Century Waterfront – Flood Defense and details the key technical findings from the evaluation of the broadest range of potential flood defense alignments that were considered as part of the Financial District & Seaport Climate Resilience Plan.

This appendix begins with an overview of the additional flood defense options that were explored but deemed not feasible as part of the Financial District and Seaport Climate Resilience Master Plan. Then, this appendix documents the range of flood defense alignments that were evaluated before arriving at the recommended flood defense proposal.

2. Additional Flood Defense Options Explored

At the onset of the Master Plan, the project team evaluated the broadest range of potential flood defense options to determine whether it was feasible to site the flood defense entirely on land. The flood defense system has two levels to protect against the different climate hazards — frequent tidal flooding and coastal storms -- and it was critical that the flood defense options selected could protect the Financial District and Seaport neighborhoods from both climate hazards.

Evaluating the broadest range of potential flood defense options was a critical first step in the planning process, as the potential historic and environmental impacts make the Master Plan subject to several local, state, and federal reviews and approvals. Wherever it is feasible to construct flood defense on-land, the current regulatory framework will not permit in-water work. “Feasible” is not only defined as technically implementable from an engineering standpoint but considers other important factors such as cost, property ownership and jurisdiction, traffic implications, and the ability to construct and/or retrofit when considered in the context of the existing urban fabric. Other key considerations, such as physical and visual access to the waterfront and displacement of open space, are also critical in determining where to site flood defense and are being explored in greater detail in *Open Space & Program Appendix* and *Access & Circulation Appendix*.

This section presents some of the additional options that were explored before arriving at the selected flood defense toolkit, including building-level adaptation, street raising, and deployable measures.

2.1 Building-level Adaptation

Building-level approaches to flood defense are challenging in terms of their feasibility and hard to apply at a study area level. Future frequent tidal flooding also makes a building-level approach not suitable in the study area. Finally, building-level adaptation leaves critical systems such as utilities unprotected, requiring additional hardening measures.

From a technical feasibility standpoint, building level adaptation in the study area is primarily constrained by the height of the design flood elevation and the lack of necessary foundation space. The red areas shown in Figure 1 illustrate the difficulty of integrating flood defense of the necessary height with the existing buildings. Key considerations when considering building-level adaptation for the study area include:

- **Foundation Requirements:** In addition to the portion visible above ground, any flood defense structure, including building-level adaptation, would have significant foundation requirements which will be challenging to site between building foundations, subway infrastructure, and other subsurface infrastructure.
- **Use of Deployable Measures to Maintain Access:** Building-level flood defense would require significant use of deployable measures to maintain connections between the street, sidewalk, and buildings. Ground raising would be necessary in conjunction with deployable measures to meet the project goal of preventing frequent tidal inundation. In Figure 1, numerous openings and entrances give a glimpse into the sheer number of deployable measures that would be needed.
- **Wave Loads & Building Impacts:** The structures closest to the waterfront are not designed to handle the load cases created by storm surges and wave action. With building-level adaptation, the outer walls would be required to bear the brunt of these loads, which could compromise the structural integrity of the building. Other options such as having “sacrificial” first floors would be very challenging to retroactively implement; building-level adaptations of this nature are generally more applicable for new construction or for a single building rather than an entire study area.
- **Accessibility, O&M, ownership, liability, and governance:** If a building becomes part of the line of defense, the building’s owner would be required to maintain the building in accordance with best flood management practice guidelines established by the Federal government. This could limit future modifications to the building. Building access points are potential weak points in the system and could create flood pathways which could impact other buildings in the area. Additionally, building-level adaptation on private property would create a dependence on private property owners to provide critical flood defense and emergency response to the neighborhood.

Figure 1: Height of building-level interventions (Background source: Google Street View)

2.2 Street Raising

While street raising has several precedents, most street raising projects are aimed at improving drainage or adapting to sea level rise alone, not providing flood defense. Several factors make street raising a non-viable option for the study area:

- **Height of intervention**: The height of interventions would make the implementation of raised streets as flood defense particularly challenging: street or sidewalk raising is only recommended when the existing grade is within four (4) feet of the DFE (i.e., closer to tiebacks).
- **Disruption to street grid**: Raising streets to protect against frequent tidal flooding would also have significant impacts to the existing street grid and connections; many locations in which streets are raised are those where there is little existing development around the raised streets. Connecting to cross streets is critical to maintaining access. In addition, access to buildings is critical for deliveries, parking maintenance, emergency response, and more.
- **Subsurface implications:** Street raising would result in additional cover placed on subsurface infrastructure, increasing the loads on subsurface utilities and making long-term operations and maintenance more challenging. Relocation of subsurface infrastructure and new access points (e.g., manholes, etc.) would be required.

2.3 Deployable Measures

Deployable measures refer to any flood defense feature that requires activation prior to providing the full level of protection (i.e., design height). Deployable measures could include "just-in-time" systems such as Tiger Dams or Hesco Barriers, plank-type systems, "flip-up" gates such as FloodBreak system, and steel roller or swing gates.

In select locations of the study area, floodgates will accompany the passive flood defense, limiting additional weight over subway tunnels and providing entrances for emergency and maintenance vehicles to reach the shoreline. However, deploying floodgates every day is not feasible. Further, the Financial District and Seaport's low-lying topography combined with strong wave action during coastal storms makes relying solely on floodgates less suitable.

- **Deployment Frequency:** The primary consideration for any deployable measure is the deployment frequency of the system. Each system requires resources to plan and execute each deployment, which makes frequent deployment burdensome. Within the study area, frequent tidal flooding under future sea level rise conditions makes deployable systems impractical. Therefore, the Master Plan prioritizes passive flood defense, which means permanently raising the height of the shoreline to +11 feet NAVD88. This ensures that deployable measures are used infrequently for coastal storms rather than up to twice daily for tidal flooding.
- **Just-in-time measures:** Just-in-time measures, pictured in Figure 2 and Figure 3, have limited application in the study area. Several limitations to just-in-time systems include:
    - **Height limitations**: Most just-in-time systems have height limitations that would be exceeded in most of the study area due to low surface elevations and high design flood elevations.
    - **Wave and load impacts**: Most just-in-time systems have limited capacity for wave and impact loads, both of which are substantial in the study area.
    - **Deployment lead time**: Just-in-time measures require a long lead time to deploy, making installing area wide protection time consuming and impractical.

- **Reliability**: Just-in-time measures are less reliable than passive systems since they require substantial resources to plan and execute deployment. Additionally, failure of individual components could lead to system wide failure.

For these reasons, just-in-time measures are not proposed as part of the Master Plan.

Figure 2: Temporary water-filled tubes (Tiger Dams) in Lower Manhattan. (Source: NYCEM)

Figure 3: Mayor De Blasio shows metal-reinforced containers (HESCO Barriers) filled with dirt near South Street in Lower Manhattan. (Source: NYCEM)

- **Plank-type systems:** Plank-type systems, pictured in Figure 4Figure 4, have greater applicability within the study area. Considerations for this type of system include:
    - **Robustness:** These systems are more robust, which means they have better wave and impact load capacity and more ability to reach the design flood elevation.
    - **Deployment lead time:** These systems require substantial time and resources to deploy.
    - **Foundation requirements:** Plank-type systems have foundation requirements similar to a floodwall (T-Wall).

  While a plank-type system could be a reasonable choice for some gate and crossing applications, the deployment time, space for storage and maintenance, and effort to implement renders area-wide use of this type of system impractical.

Figure 4: Plank-type system installed at (Source: NYCEM)

- **Flip-up gates**: Flip-up gates have limited application in the study area. Considerations for this type of system include:
    - **Robustness:** These systems are more robust than just-in-time measures, which means they have better wave and impact load capacity and more ability to reach the design flood elevation. However, they are not recommended for areas directly exposed to higher wave conditions and potential for debris impact.
    - **Height considerations:** For many locations in the study area, the required height for the gates would exceed typical design conditions for this type of system. The height of these systems is also directly related to the width since the gates need to be stored horizontally in the foundation footprint (see next bullet).
    - **Foundation requirements:** Foundations also tend to be wider than the other solutions since they need to encompass the full height plus edge beams and mechanical systems. Due to horizontal constraints in many locations in the study area, a narrower foundation is advantageous.

  As with the plank-type system, flip-up gates could be used in combination with raised grades for some gate and crossing applications in the study area; however, due to the low-lying elevation throughout most of the study area, as well as the wave climate compared to elsewhere in Lower Manhattan, these measures are recommended for use only sparingly as part of the Master Plan.

- **Roller and swing gates**: Roller and swing gates provide robust access with a good track record of successful deployment. These systems are a preferred choice for access points and crossings. However, these systems are not intended for area-wide use due to the same concerns noted for flip-up gates: due to the low-lying elevation throughout most of the study area, as well as the wave climate compared to elsewhere in Lower Manhattan, these measures are only proposed sparingly as part of the Master Plan.

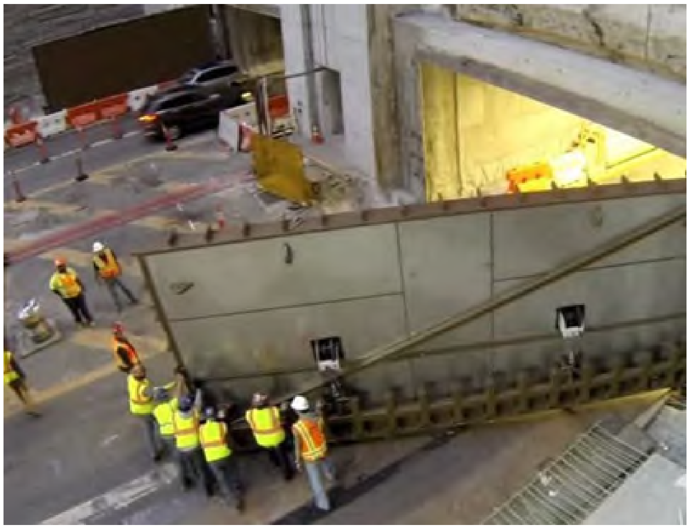

Figure 5: Swing-hinged gate at Hugh L. Carey tunnel entrance

Figure 6: Over-head trolley roller gate at Bay Park Wastewater Treatment Plant. (Source: Arcadis)

3. Flood Defense Walkthrough

Across the study area, on-land options and different shoreline extension lengths – minimal and wider – were tested to understand how well different options meet the project's goals and priorities. This section discusses the flood defense options studied across each portion of the study area, as shown in Figure 7.

- **The Southern Tie-In to the Battery Maritime Building** portion has key maritime assets and ferry terminals, including the Whitehall Ferry Terminal and the Battery Maritime Building.
- **The Battery Maritime Building to Wall Street** portion houses the heliport and Pier 11, as well as the transition of the FDR from at-grade to elevated viaduct.
- **The Wall Street to the Brooklyn Bridge** portion has the historic, low-lying South Street Seaport district as well as Pier 17, which houses the newly reconstructed Tin building, and the tie-in to higher ground adjacent to the Brooklyn Bridge.

These unique considerations across each portion determine what is technically feasible when deciding how and where to place the flood defense system.

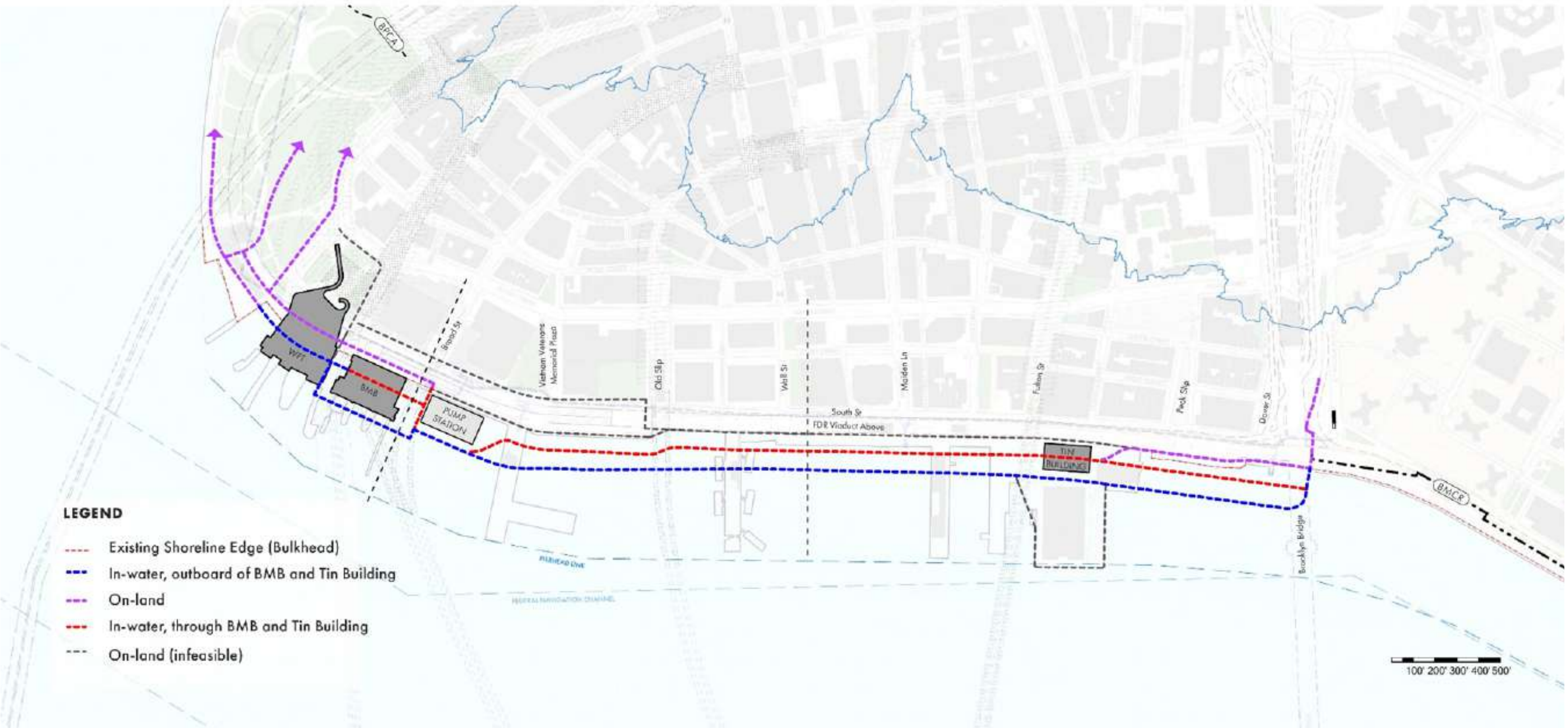

Figure 7: Study area overview

3.1 Southern Tie-In to the Battery Maritime Building

In this portion of the study area, the key considerations that determine how the flood defense is integrated into the waterfront include:

- Maintaining Staten Island Ferry service at the Whitehall Ferry Terminal (WFT)
- Preserving the Battery Maritime Building (BMB), a historical landmark
- Navigating a complex system of underground infrastructure, including the Battery Park Underpass, subway stations, and subway tunnels

The flood defense alignment must also tie into higher ground in this area, as described in *Chapter 5: A Resilient 21st Century Waterfront – Flood Defense – Tie-Ins*.

3.1.1 On-Land Option

In the southern portion of the study area, the project team analyzed two on-land options (Figure 8):

- Inland of the Battery Park Underpass
- Along the Battery Park Underpass

Figure 8: On-land alignment options between the southern tie-in and the Battery Maritime Building (Background source: Google Earth)

Inland of the Battery Park Underpass

An option inland of the Battery Park Underpass would aim to avoid direct impacts to both the Whitehall Ferry Terminal and the Battery Maritime Building. To achieve this, the flood defense system would have to be integrated with adjacent building podiums north of South Street and across or through Peter Minuit Plaza. With several subway tunnels (4/5 train, R/W train), the South Ferry Loop, and a subway station (Whitehall Station) underneath the plaza, this option would encounter significant technical obstacles underground. An overview of the subsurface infrastructure in Reach A is shown in

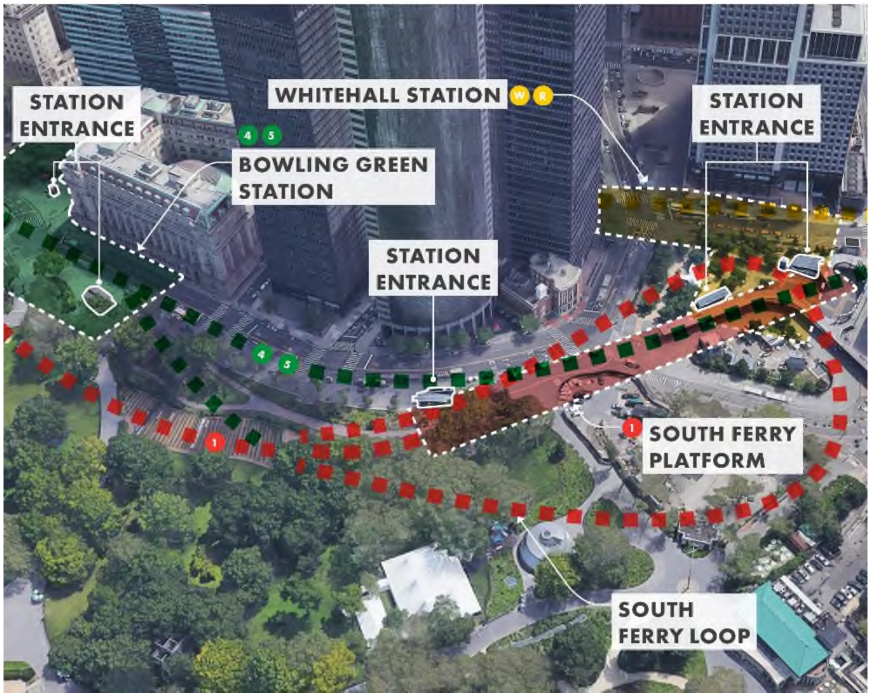

Figure 9.

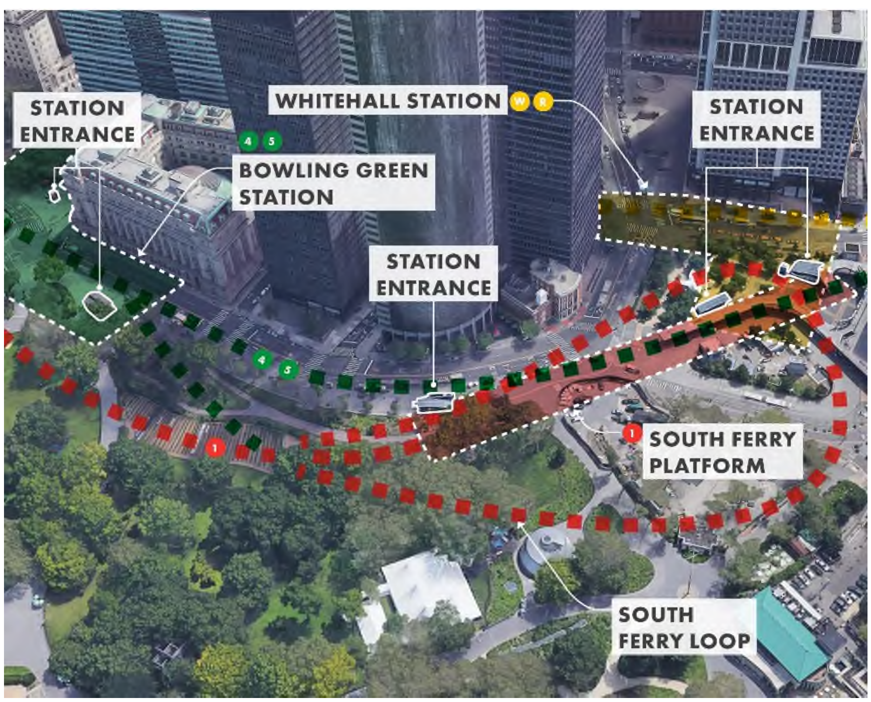

Figure 9: Overview of key subsurface infrastructure between the southern tie-in and Battery Maritime Building (Background source: Google Earth)

This alignment precludes the Master Plan from achieving the target design flood elevation for frequent tidal flooding as the Battery Park Underpass, subway stations, and critical maritime infrastructure would remain vulnerable.

Additional technical challenges that preclude this alignment are described in further detail below:

South Ferry Loop: Per discussions with MTA, the South Ferry Loop is used daily in support of the 4/5 train operations and cannot be decommissioned or moved. The South Ferry Loop presents several challenges. First, the South Ferry configuration makes crossing the tunnel at 90 degrees difficult–multiple crossings or long spans of bridging structure would likely be required. Moreover, the South Ferry Loop is less than 5 feet from the surface in some locations, presumably above the groundwater table. If any portion of the tunnel is located on the water side (floodable side) of the flood defense system, it would require extensive floodproofing, structural retrofitting, or reconstruction to meet performance standards and to prevent it from becoming a flood pathway into the protected area. These modifications would likely require taking the tunnel out of service for an extended period. Overall, any alignment that impacts the South Ferry Loop would impact MTA operations, have significant feasibility concerns, and add significant costs to the project beyond the core resilience work. For these reasons, the Master Plan presents an alignment that keeps the loop on the protected side of the line of defense.

Whitehall and South Ferry Subway Stations: The Whitehall and South Ferry subway stations cannot be moved within the timeline need to realize flood protection. Like the South Ferry Loop, the Whitehall and South Ferry subway stations present several challenges. They are located very close to the surface and their sizes and configurations would require long, expensive spans. While the stations have previously undergone floodproofing, they were not designed to resist forces associated with being an integral component of a flood defense system. For these reasons, as well as to maintain access, the project team proposes an alignment that protects subway stations. If any portion of the stations were to be located on the water side of the flood defense system, it would require extensive structural retrofitting or reconstruction to meet performance standards and to prevent it from becoming a flood pathway into the protected area by other means. These modifications would require taking the stations out of service for an extended period or otherwise disrupt normal operations.

This option would also rely heavily on use of deployable gates as well as selective building-level flood defense measures to maintain access to streets and buildings. Building-level measures in this area are constrained by the sheer height of the target design flood elevation and the lack of necessary foundation space due to the dense urban fabric of the area. Key considerations are described in *Building-level Adaptation.*

Along the Battery Park Underpass

The project team studied the feasibility of placing the flood defense along the Battery Park Underpass, which could take several forms:

- **Incorporating the Battery Park Underpass into the line of flood defense:** Incorporating the Battery Park Underpass into the line of defense, such as placing a floodwall above or along the centerline of the underpass, may be possible but would require some level of demolition and reconstruction with likely significant service disruptions to traffic.
- **Repurposing the structure itself:** Repurposing the structure itself, such as relying on the existing outer wall or center divider, to be part of the flood alignment would require significant structural modifications or reconstruction. These modifications or reconstruction would likely include new foundation support, structural reinforcement of the tunnel, and waterproofing; these measures would result in significant service interruptions to traffic, to above ground uses, and to adjacent uses.

- **Build an independent flood defense structure "around" the Battery Park Underpass:** Incorporating the Battery Park Underpass into the line of defense, such as placing a floodwall above or along the centerline of the underpass, may be possible but would require some level of demolition and reconstruction with likely significant service disruptions to traffic. Building an independent flood protection structure would still result in service disruptions and may result in the loss of one lane of traffic, as shown in Figure 10.

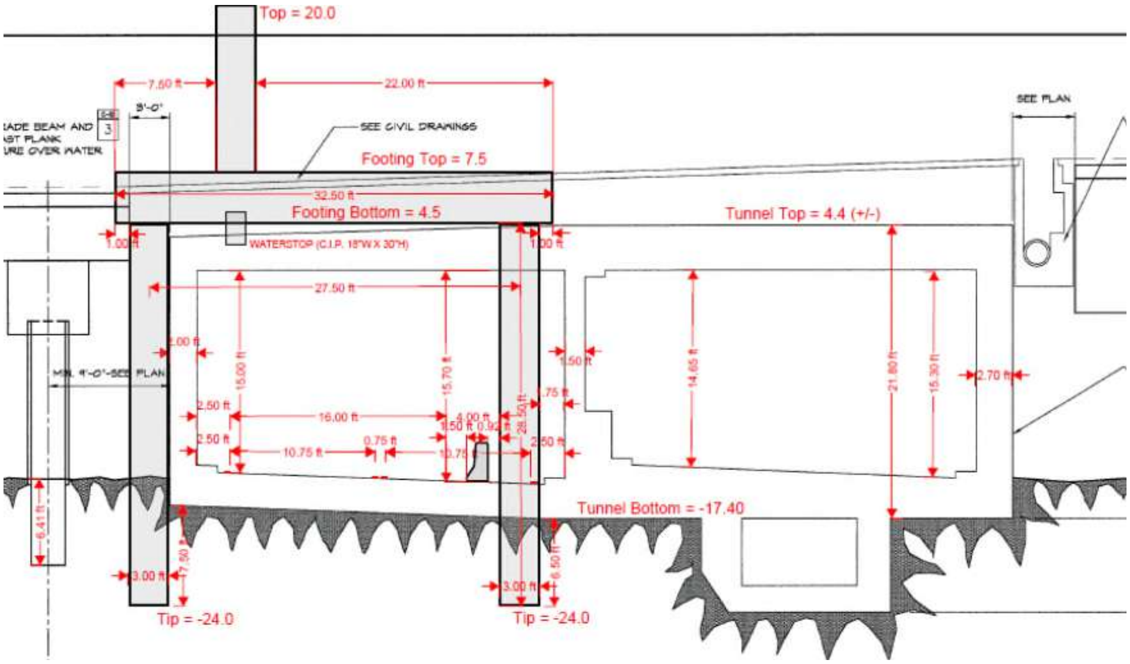

Figure 10: Schematic of potential modifications to the Battery Park Underpass needed to incorporate flood defense (representative cross section of the Battery Park Underpass; not intended for design)

For the segment along the Whitehall Ferry Terminal, following the Battery Park Underpass would not require any shoreline extension. However, this option would require partial or full reconstruction of the Whitehall Ferry Terminal. The Whitehall Ferry Terminal would still be located on the water side of the flood defense alignment, which would leave it vulnerable to flooding and require additional building-level measures for the structure to be protected.

For the segment along the Battery Maritime Building, following the Battery Park Underpass would allow impacts to the historic structure to be greatly minimized. It would leave the Battery Maritime Building on the water side of the flood protection system, requiring additional building-level measures to protect the structure. In addition, the flood defense system would obscure views of and reconfigure access and connections to the first floor of the Battery Maritime Building's South Street façade.

Based on the technical analyses, the project team recommended that the flood defense alignment be located on the water side of the South Ferry Loop, the subway stations, and the BPU to minimize impacts on those assets and services and protect them from flooding.

3.1.2 Battery Maritime Building

The Battery Maritime Building was a key driver in determining where to construct the flood defense alignment. The project team studied three options:

- Upland of the Battery Maritime Building, along the Battery Park Underpass
- Through the Battery Maritime Building
- Wrapping the Battery Maritime Building

Upland of the Battery Maritime Building, along the Battery Park Underpass

As mentioned above, the project team evaluated whether the flood defense system could be sited on-land upland of the Battery Maritime Building and run through the Battery Park Underpass. While this option minimizes fill in the East River and minimizes interference with multiple utilities, it removes one lane of traffic from the Battery Park Underpass. It also complicates and potentially reduces the ability for emergency and other services to access the first floor for the building, requiring modifications for elevated street access to the second floor of the building. Further, the Battery Maritime Building would remain exposed to flooding and would require building-level flood defense including structural reinforcement for future storm wave impacts. Given the Battery Maritime Building is a landmarked building, adapting the structure for future coastal storms and sea level rise would be challenging. Ultimately, this option was not recommended as part of the Master Plan because of the expected impacts to the Battery Park Underpass, such as losing a lane of traffic, impacts to building access, and the additional necessary independent hardening of the Battery Maritime Building.

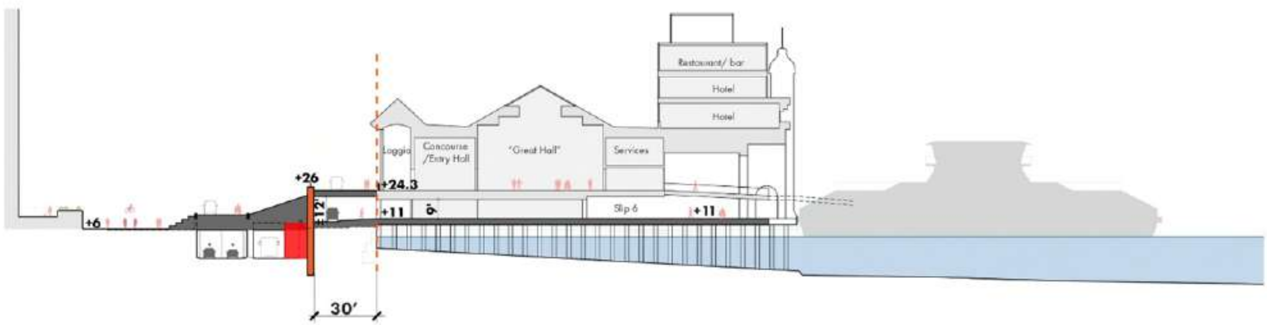

Figure 11: Flood defense alignment through the Battery Park Underpass

Through the Battery Maritime Building

The project team studied whether the flood defense system could pass through and be integrated into the Battery Maritime Building. This option avoids impacts to the Battery Park Underpass, maintains vehicle access to maritime uses, preserves public waterfront access, and preserves the Battery Maritime Building façade. However, a portion of the Battery Maritime Building would remain exposed to flooding while other portions will require a degree of reconstruction. Due to the required height of the flood defense, modifications to both the first and second floor would be required. Substantial portions of the outboard portion of the building would require hardening including structural reinforcement for future storm wave impacts for both the ground and second floors. The Battery Maritime Building is located over several subway tunnels and an alignment through the building would require long bridging spans over the tunnels: constructing a long structural span inside the existing building envelope would be a substantial constructability challenge. Additionally, some in-water fill would be required. Ultimately, this option was not recommended as part of the Master Plan due to the complexity of constructing flood defense through this historic landmarked building and effectively hardening the water side of the building.

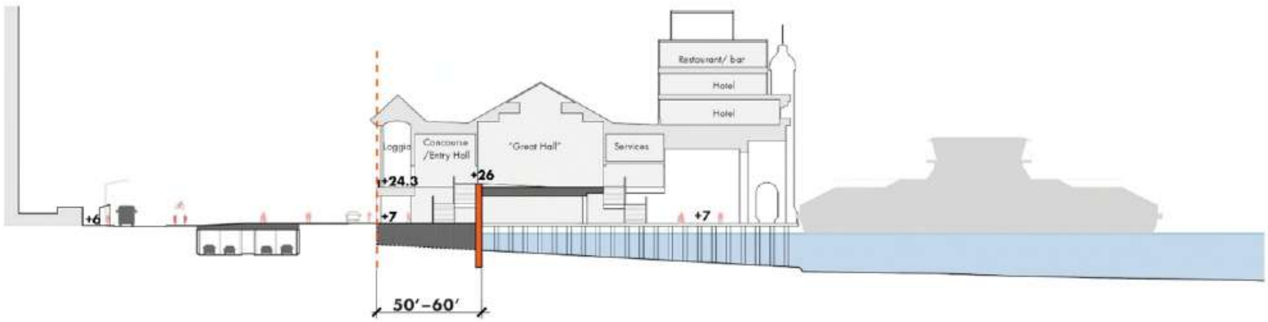

Figure 12: Flood defense alignment through the Battery Maritime Building

Around the Battery Maritime Building

The project team studied whether the flood defense system could go outboard of the Battery Maritime Building, providing passive flood defense for the entire building. This option would not impact the Battery Park Underpass and would facilitate a continuous waterfront esplanade throughout the study area. A significant amount of fill would be required. The building would no longer function as a ferry terminal and maritime docks would need to be moved further out into the river or relocated to an alternate ferry facility. The western façade of the building would be preserved, and the eastern façade would be preserved with visual impacts. Existing street level access to the building would also be preserved.

Ultimately, the Master Plan proposes this option because it protects the historic Battery Maritime Building. While the use of the building as a ferry terminal is not preserved (i.e., a new ferry terminal will need to be constructed to replace the current maritime uses), the facility as is will see monthly impacts due to sea level rise by the 2050s and daily by the 2080s, impacting the functionality of the facility. The facility itself can be adapted for complementary public uses, such as an extended waiting hall, food hall, or other space to support the adjacent ferry terminals. Governors Island Ferry and other services will be relocated to new maritime facilities. A new ferry terminal is proposed just north of the Battery Maritime Building to provide a resilient gateway. This option also allows the subway tunnels to be crossed with shorter spans and better access, improving constructability. As the Master Plan advances towards implementation, the amount of fill needed in this option will require additional coordination with regulatory agencies for permitting and historic impacts will be evaluated and coordinated with agencies.

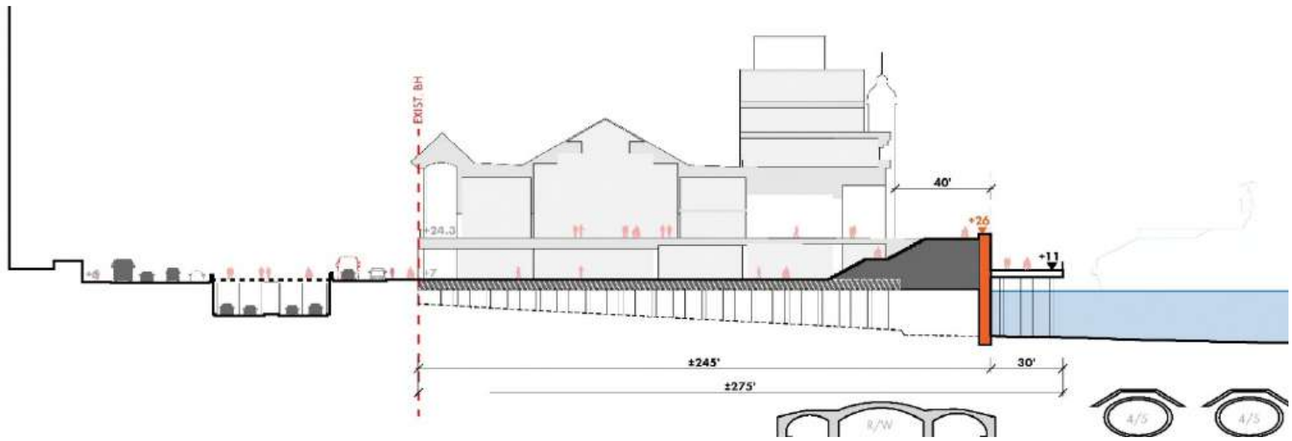

Figure 13: Flood defense alignment outboard of the Battery Maritime Building

3.2 Battery Maritime Building to Wall Street

For this portion, the key considerations in integrating the flood defense into the waterfront include:

- Maintaining the regional transportation functions of the FDR Drive including the transition of the elevated portion of the FDR Drive into the Battery Park Underpass.
- Maintaining maritime and ferry services and access to these services for all users.
- Maintaining continuous waterfront access.
- Crossing subway tunnels.
- Crossing underground utilities such as the interceptor and oil-o-static line.

In this portion, an on-land alignment that accomplishes the project goals is infeasible due to the space constraints posed by the FDR Drive. The roadway is at-grade throughout much of this portion, and any flood protection needs to go on the water side of the roadway to protect the asset, including the entrance to the Battery Park Underpass. Placing flood protection on the water side also avoids the building level issues discussed above. To reach the design flood elevation and provide universal access, the Master Plan recommends an alignment that minimizes fill to the extent necessary to meet project goals.

3.3 Wall Street to Brooklyn Bridge

In this portion of the study area—the most vulnerable area in the study area due to low-lying elevations in the Seaport District— key considerations for integrating flood defense into the waterfront include:

- Protecting and preserving the historic South Street Seaport District.
- Understanding the role and function of the FDR Drive viaduct in relation to placing flood defense infrastructure.
- Maintaining maritime and ferry services and access to these services for all users.
- Maintaining continuous waterfront access.
- Crossing subway tunnels.
- Crossing underground utilities such as the interceptor and oil-o-static line.

The project team explored on-land and in water options along this portion of the study area.

3.3.1 On-Land Option

The project team studied the feasibility of an entirely on-land alignment following the existing shoreline. With the FDR Drive viaduct as-is, there is not sufficient clearance between the FDR Drive, the existing shoreline, and the Tin building's foundations to place flood defense infrastructure with its foundation requirements, as pictured in Figure 14. It is also infeasible to run an alignment under the FDR Drive here due to the vertical and horizontal space constraints, as described below.

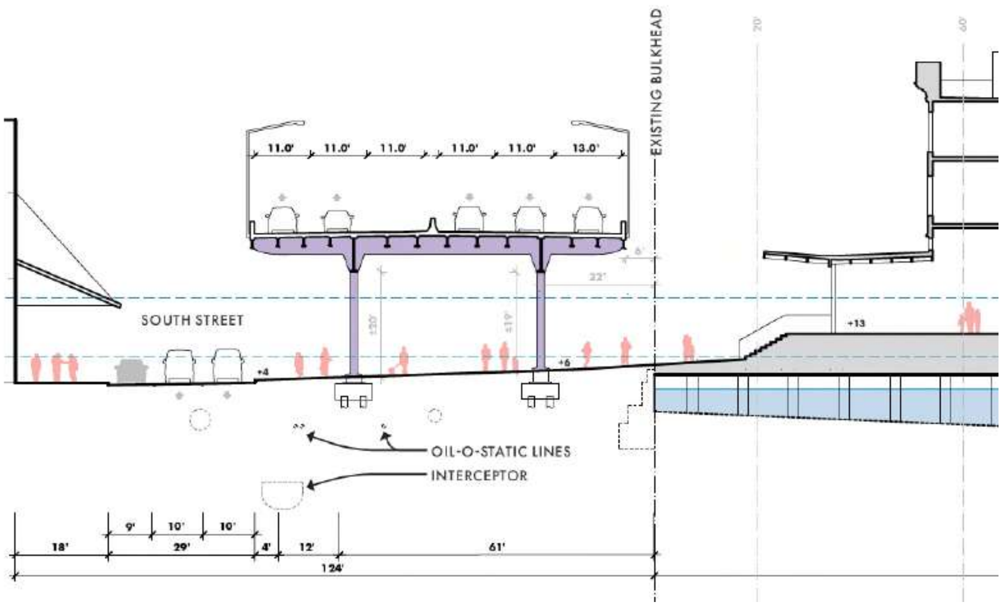

Figure 14: There is only about 6 feet of clearance between the FDR Drive viaduct and the existing bulkhead near the Tin Building.

Constructing Beneath the FDR Drive viaduct

Given the limited available space to construct the flood defense on land, the project team evaluated the feasibility of constructing a floodwall with limited floodgates for access beneath the FDR Drive viaduct. In both instances, the result of the analysis demonstrated that vertical and horizontal clearance limits the ability to construct flood defense beneath the FDR Drive viaduct in the study area.

Vertical Clearance

The height of the floodwall needed to protect the study area from the 2100 100-year storm, reaching an elevation of 23 feet NAVD88, poses significant challenges to the vertical clearance under the FDR Drive viaduct. Figure 15 shows the overlay of the elevation of the FDR Drive viaduct and the vertical constraint. As demonstrated in the graphic, there is insufficient clearance under the FDR Drive viaduct to accommodate the flood defense system along the entire alignment except for a stretch of about 750 feet between Piers 11 and 15. Even where vertical clearance allows for some type of flood defense to be located under the FDR Drive viaduct, several factors still pose significant challenges to the successful implementation of such an alignment:

- **Ensuring critical assets are protected**: Placing an alignment of this height underneath the FDR Drive viaduct would not protect the eastern support columns for the highway, exposing them to wave and impact loads during coastal flood events. The entire superstructure would also be exposed to more salt spray, likely increasing maintenance for the highway support structure.

- **Increased technical complexity**: To connect the section where vertical clearance allows for an alignment under the FDR Drive viaduct to the neighboring section of alignment, a transfer from outboard alignment to inboard alignment and back to outboard alignment would be required. This necessary connection adds technical complexity to the alignment and would add cost without increasing the benefits of the flood defense system.

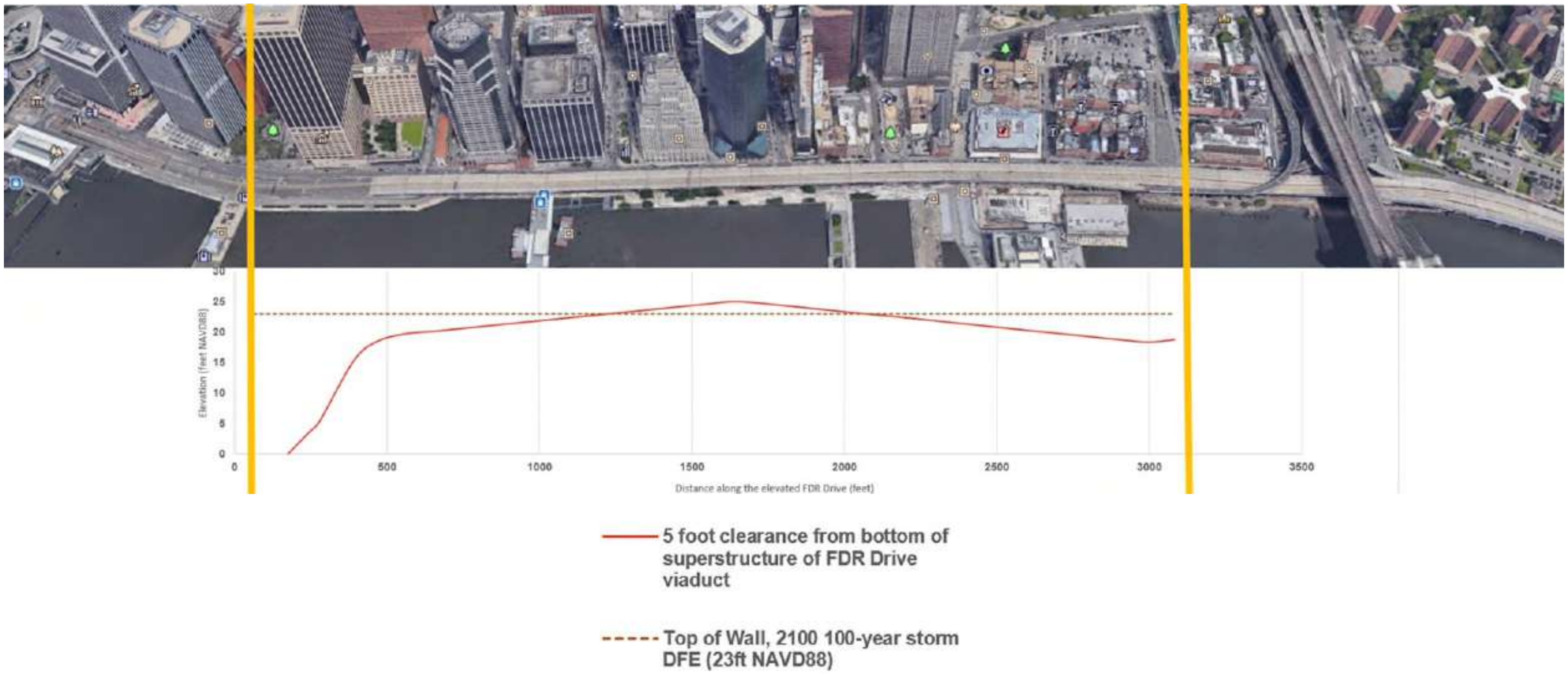

Figure 15: FDR Drive viaduct vertical clearance challenges (Background source: Google Earth).

When the red line is below the dashed brown line, there is insufficient clearance between the bottom of the superstructure and the top of the flood defense alignment; in these locations the alignment cannot fit below the viaduct. When the red line is above the dashed brown line, there is sufficient clearance between the bottom of the superstructure and the top of the flood defense alignment; in these locations the alignment can fit below the viaduct.

Horizontal Clearance

Limited horizontal space presents challenges to construction under the FDR Drive viaduct. Table 1 and Figure 16: Approximate FDR Drive Dimensions (from Brooklyn Bridge-Montgomery Coastal Resilience) summarize the approximate horizontal dimensions under the FDR Drive viaduct in the study area. Considering the required offset from the FDR Drive viaduct footings, only 13 feet of horizontal space is available under the FDR Drive viaduct.

Table 1: Approximate Horizontal Dimensions Under the FDR Drive

Dimension	Approximate Measurement
Between FDR footing column clearance offsets	13 ft
Between FDR footing columns	23 ft
Between FDR footing column centerlines	35 ft
Subgrade footing column	15 ft x 12 ft
Offset from FDR footing column	5 ft

Providing Constant Protection from Tidal Flooding

Due to low ground elevations in the area, there is not enough space from the facades of the buildings on South Street to the mid-point under the FDR Drive viaduct (where the flood defense measure would be) to achieve the necessary passive level of protection. With a ground elevation of about 6 feet NAVD88 (lower at times), a passive design flood elevation of 11 feet NAVD88, and a horizontal distance of approximately 90 feet, achieving passive protection by raising the road would not be possible because the road slope would be above the acceptable upper limit of 5% (1:20 slope for universal access).

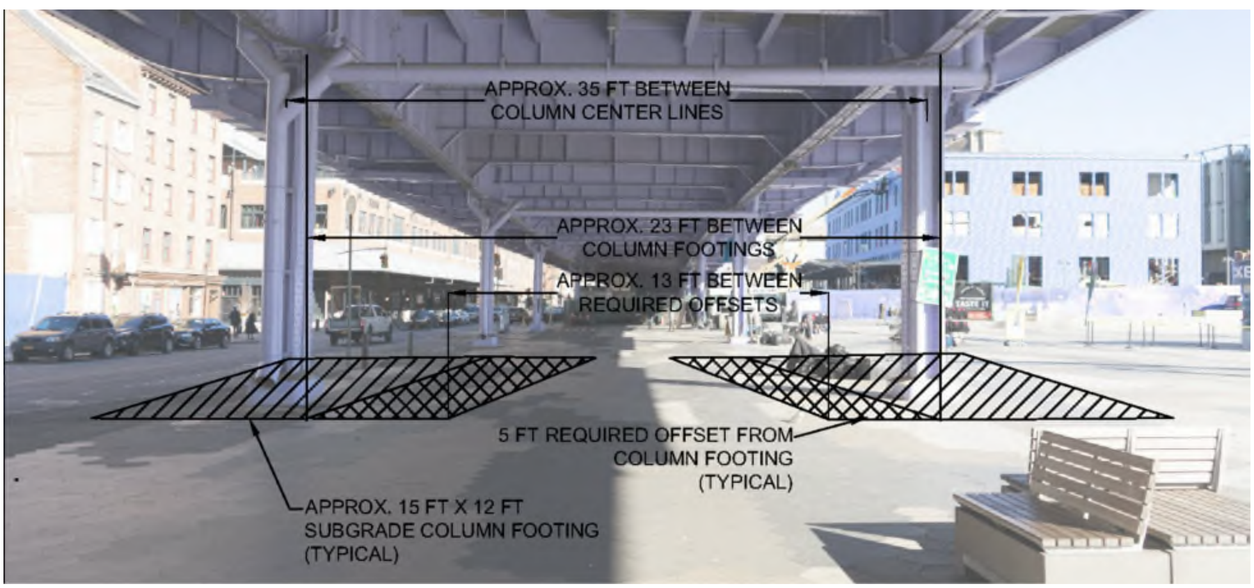

Figure 16: Approximate FDR Drive Dimensions (from Brooklyn Bridge-Montgomery Coastal Resilience)

3.3.2 Tin Building

The Tin Building was a key driver in determining where to construct the flood defense alignment. Once it was determined that there was insufficient space to construct the flood defense between the FDR Drive viaduct and the Tin Building, the project team studied two options:

- Through the Tin Building
- Between the Tin Building and Pier 17

Through the Tin Building

The project team evaluated the feasibility of running the flood defense alignment through the Tin Building. While this option minimizes fill in the East River and minimizes interference with multiple utilities, the Tin Building is a recently reconstructed landmark building, and adapting it to accommodate flood defense running through it would be challenging. Moreover, any alignment through the building would likely disrupt building operations. The Tin Building was also elevated when it was reconstructed; its first floor elevation is about 13 feet NAVD88, which places it above the frequent tidal flooding design elevation for this project. Additionally, this option would leave part of the Tin Building exposed to flooding from coastal storms, requiring independent flood defense. While Pier 17 is outboard of the flood defense, it was built recently and is at a significantly higher elevation. Though Pier 17 is still vulnerable to coastal storms, it will not be impacted by monthly tidal flooding within this century.

Ultimately, the project team concluded that this option was not feasible due to the level of disruption to the newly constructed building, especially given that it is already elevated beyond this project's tidal flooding design elevation.

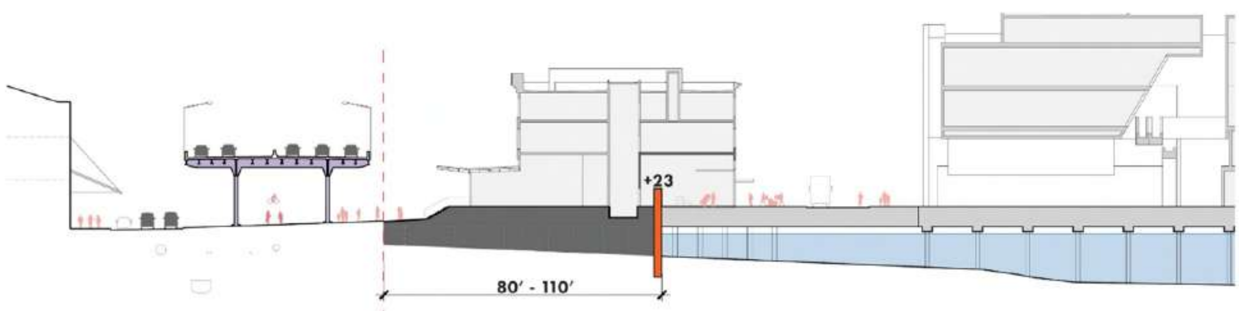

Figure 17: Flood defense alignment through the Tin Building

Between the Tin Building and Pier 17

The project team evaluated constructing the flood defense alignment between the Tin Building and Pier 17. This option protects the Tin Building without disrupting internal operations. An alignment between the buildings would be a passive system with deployable gates to maintain emergency vehicular access. Private vehicles supporting these facilities are limited to dedicated access driveways to ensure pedestrian safety.

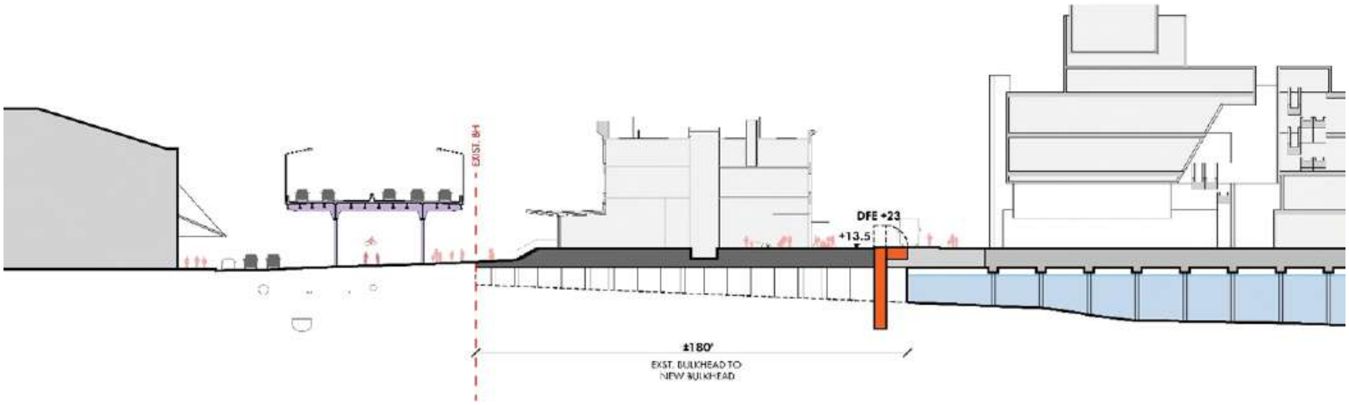

Figure 18: Flood defense alignment between the Tin Building and Pier 17 building

3.3.3 Tie In Near Brooklyn Bridge

Between Pier 17 and the Brooklyn Bridge, the key considerations determining how the flood defense is integrated into the waterfront include:

- Understanding traffic connections to and from the Brooklyn Bridge.
- Understanding the role and function of the FDR Drive and South Street in relation to placing flood defense infrastructure.
- Potential impacts to intertidal habitat near Brooklyn Bridge Beach.
- The proximity to Brooklyn Bridge to Montgomery Street Coastal Resilience and the ability to leverage on-going capital investments as part of the northern tie-in.

The project team evaluated the technical feasibility of an entirely on-land flood defense system following the existing shoreline. While this area still has constraints such as the FDR Drive viaduct and underground utilities, there are no maritime transportation functions that must be maintained in this area, potentially allowing a different approach to waterfront access. Moreover, the intertidal habitat (as described in the Ecology Appendix), as well as proximity of the Brooklyn Bridge support abutments adds additional complexity to constructing the flood defense alignment.

On-Land Option

The project team evaluated the feasibility of constructing the entire flood defense alignment on land in this portion of the study area. However, analysis revealed that, without modifications to South Street, there is not enough space from the curb to the existing shoreline (where the flood defense measure would be) to achieve the necessary passive level of protection while maintaining a slope below the acceptable upper limit of 5% (1:20 slope for universal access). As a result, the Master Plan does not propose a fully on-land option in this stretch.

Tapered Shoreline Option

Since a fully on-land option was deemed infeasible, the project team analyzed the minimum extension into the East River needed to construct flood defense and maintain continuous waterfront access. The lack of existing maritime assets in this portion of the study area allowed the project team to approach this area differently. North of Peck Slip, the flood defense is proposed closer to the existing bulkhead to minimize hydrodynamic and ecological impacts to the unique zone under the Brooklyn Bridge. This short segment is the only place where the Master Plan proposes a new bulkhead and exposed floodwall.

Achieving the passive design flood elevation while maintaining universal access to the waterfront from South Street drives the width of the shoreline extension between Pier 17 and Peck Slip. North of Peck Slip, the extension tapers back to shore, minimizing potential impacts to intertidal habitat and hydrodynamic impacts (e.g., increased water speeds / scour) to the Brooklyn Bridge support abutments.

Aquatic Sampling and Testing

The first year of aquatic sampling & testing demonstrated that there is intertidal beach habitat at the abutment of the Brooklyn Bridge. Given the Master Plan's goal to minimize impact to existing aquatic species, the project team proposed a detached, continuous esplanade along the waterfront to minimize potential impacts to existing intertidal habitat. More information on the aquatic species and habitat within the study area can be found in the *Aquatic Sampling & Testing Appendix*.

Hydrodynamic Modeling

Moreover, given the aster plan's proximity to the Brooklyn Bridge, a sensitivity test was conducted via hydrodynamic modeling to ensure the shoreline extension did not cause undesired impacts to the Brooklyn Bridge footings (e.g., scour). As described in the *Hydrodynamics Appendix,* the project team studied a 30-foot extension, 80-foot extension, and 160-foot extension. The 30- and 80-foot extensions had minimal impacts, while the 160-foot extension has undesirable impacts to speed of the water. Tapering the extension as it gets closer to the Brooklyn Bridge to create a cove reduces these impacts.

4. Flood Defense Proposal

The diagram below illustrates the proposed flood defense system proposal as presented in the Master Plan. This is a primarily passive flood defense system complemented by the limited use of flood gates. Where flood gates are proposed, the Project Team recommends utilizing roller gates given their track record of successful deployment. The flood defense system has two levels to protect against the different climate hazards — frequent tidal flooding and coastal storms. This proposal represents the option with the smallest in-water footprint that still achieves the projects goals. Additional detail can be found in *Chapter 5: A Resilient 21st-Century Waterfront – Flood Defense*.

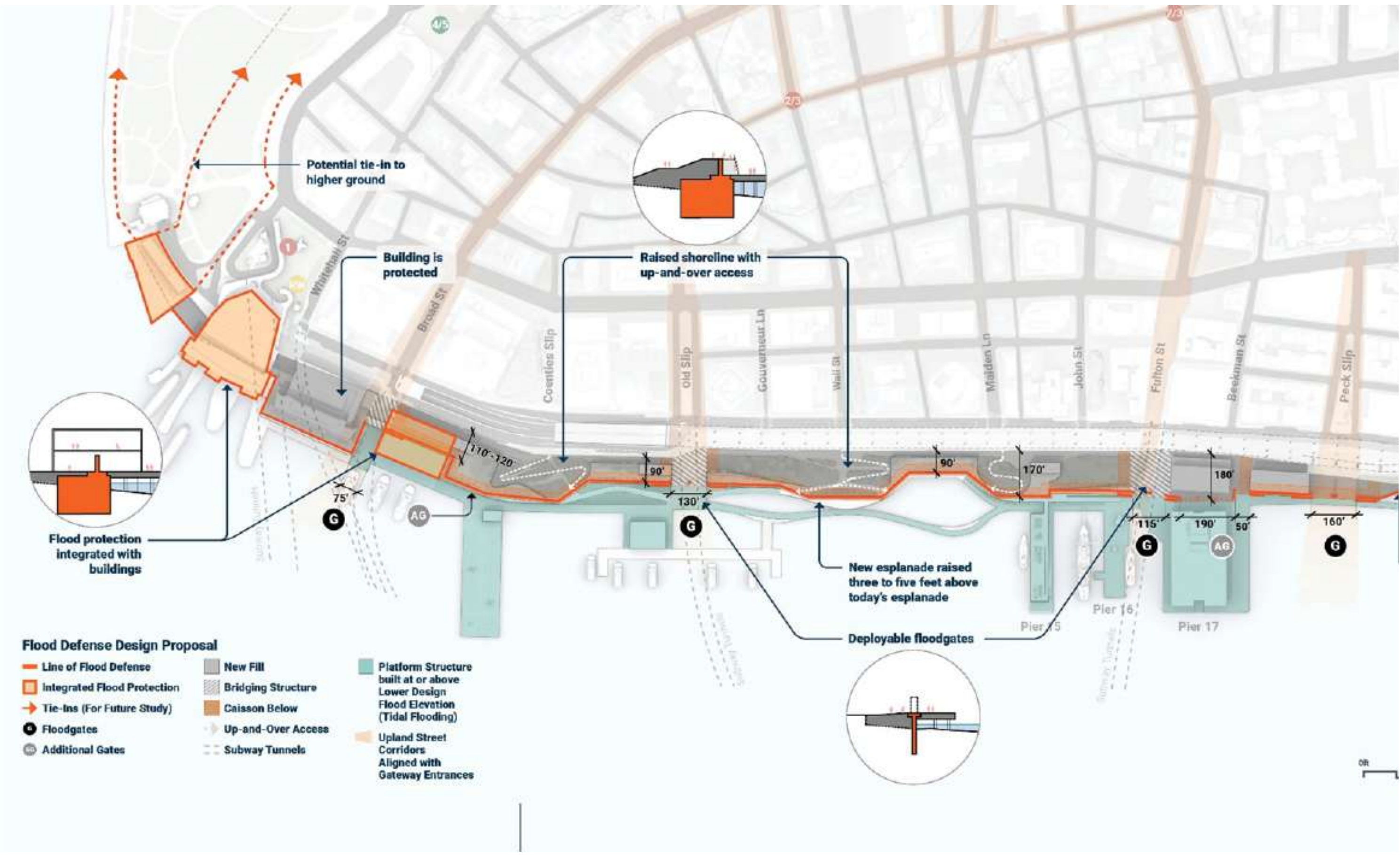

Figure 19: Flood defense design proposal