Thruway Authority
New York State Department of Transportation
Metro-North Railroad

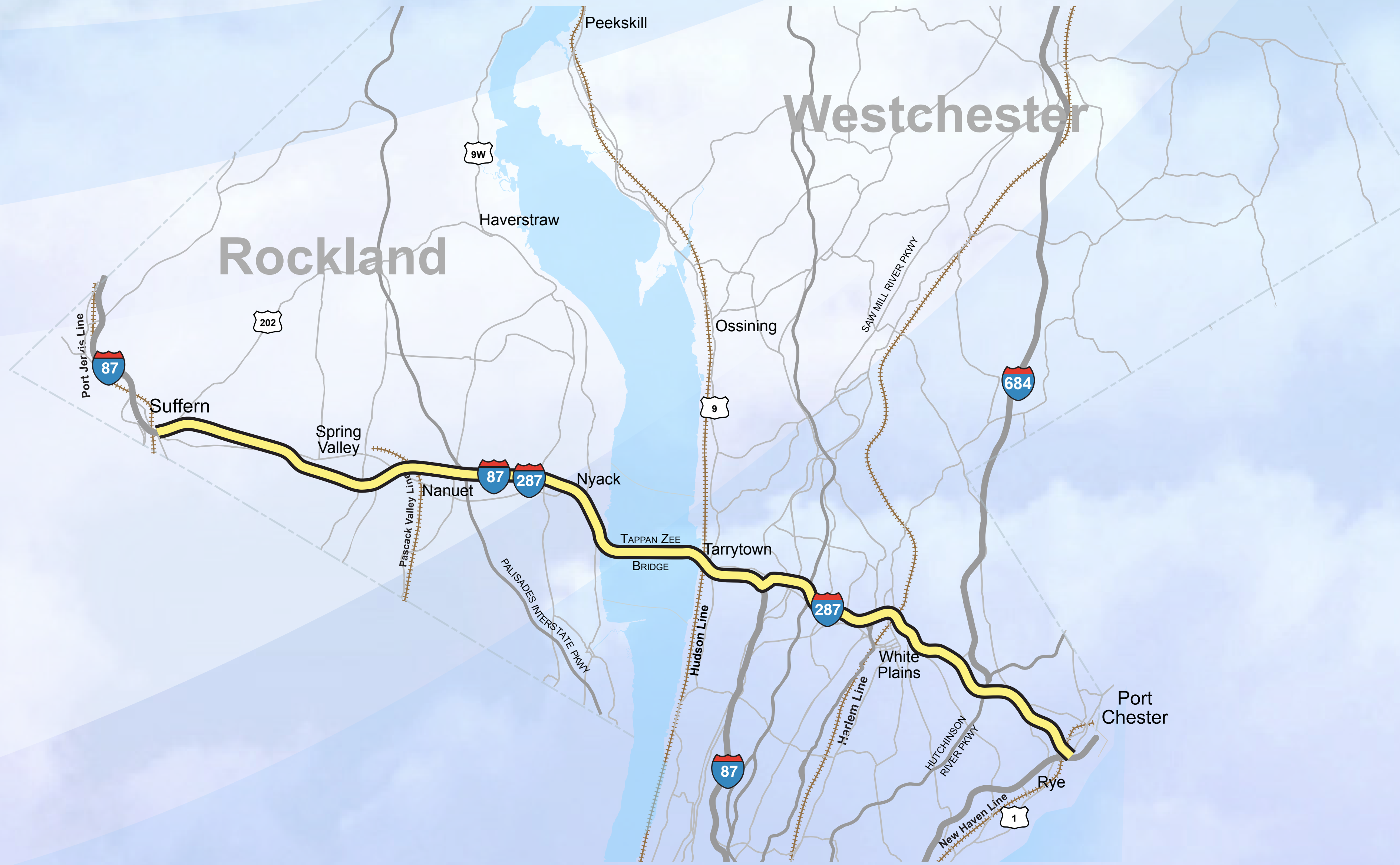
New York State Department of Transportation
New York State Thruway Authority
Metropolitan Transportation Authority/Metro-North Railroad

Tappan Zee Bridge/I-287 Corridor Project

Feasible Alternatives for the Replacement Tappan Zee Bridge (TP9)

DRAFT 3

March 2011



Executive Summary

The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) – co-lead agencies, the New York State Department of Transportation (NYSDOT), the New York State Thruway Authority (NYSTA), and MTA/Metro-North Railroad (MNR), a subsidiary of the Metropolitan Transportation Authority (MTA) – the Project Sponsors, are preparing an *Environmental Impact Statement for the Tappan Zee Bridge (TZB)/I-287 Corridor Project* in Rockland and Westchester Counties, New York (NY).

One of the key steps in preparation of the *EIS* is the development and refinement of alternatives. As this project has transit, bridge, and highway elements, the process of defining the alternatives is documented in a number of studies and technical papers (*TP*) by the Project Sponsors:

- *Transit Alignment Options Report* (*TAOR*)
- *Highway Improvements Report* (*HIR*)
- *Bridge Options Development Report* (*TP 1 - BODR*) and its successor *Feasible Alternatives for the Replacement Tappan Zee Bridge* (*TP 9*, this *report*).

The purpose of this report is to narrow the list of alternatives to be analyzed in the *EIS*, but not to exclude any environmentally preferable alternative. That list starts with the six Replacement Tappan Zee Bridge (RTZB) options recommended for further consideration in the *BODR* – 3 single-level options and 3 dual-level options.

The limits of evaluation of the options considered in this report extend from Interchange 10 in Rockland to Interchange 9 in Westchester. Recommendations are based on the evaluation of Engineering, Transportation, Environmental and partial Cost criteria as listed in Table ES1 and are drawn from data developed for the following supporting technical documents:

- *TP 2* *Foundations for the Feasible Alternatives for the RTZB*
- *TP 3* *Risk Assessment of the Feasible Alternatives for the RTZB*
- *TP 4* *Possible Bridge Types for the RTZB*
- *TP 5* *Cost Estimate for the Feasible Alternatives of the RTZB*
- *TP 6/7* *Construction of the Feasible Alternatives for the RTZB and Landings*
- *TP 8* *Visualizations of the Feasible Alternatives for the RTZB*
- *TP 11* *Shared Use Path Report*

Each option includes 8 general purpose highway lanes, 2 Bus Rapid Transit (BRT) lanes, 2 Commuter Rail Transit (CRT) tracks and a shared use path (SUP) on the north side. BRT is included in either a Busway or in high occupancy vehicle/high occupancy toll (HOV/HOT) lanes.

Report Methodology

This report is the second step in a 3-step process that began with selection of 6 optional configurations for the RTZB from numerous possible bridge arrangements, a process documented in the *Bridge Options Development Report* (*BODR*). In Step 2, this report uses the project evaluation criteria (Table ES 1) to narrow this list to two alternatives – a single-level crossing and a dual-level crossing for further evaluation in step 3, the *Draft EIS*

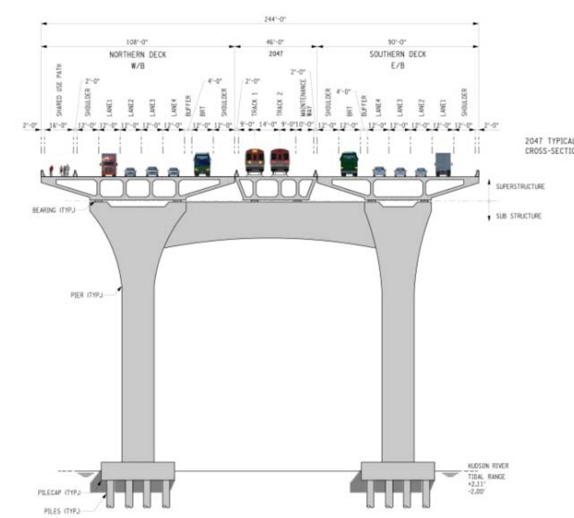
This report studies the crossing from Interchange 10 in Rockland, through Interchange 9 in Westchester. It assumes a Cable-Stayed Main Span, though an Arch Span is feasible and wouldn't change the conclusion. Both Short and Long Tunnel CRT connections to the Hudson Line are considered and rail loads are limited to maintenance train loading. The rudimentary piling plan developed for each option employs 4-foot diameter piles throughout.

The report identifies requirements for the RTZB including design criteria and vertical and horizontal alignment and reviews foundation, bridge type, and construction issues and transitions at the landings. The report introduces first the single-level options then evaluates them using the engineering, transportation, environmental and cost criteria. The process is repeated for the dual-level options. Single Level Option 3 and Dual Level Option 5 (Figure ES 1) are recommended as the RTZB alternatives to be evaluated in the *DEIS*.

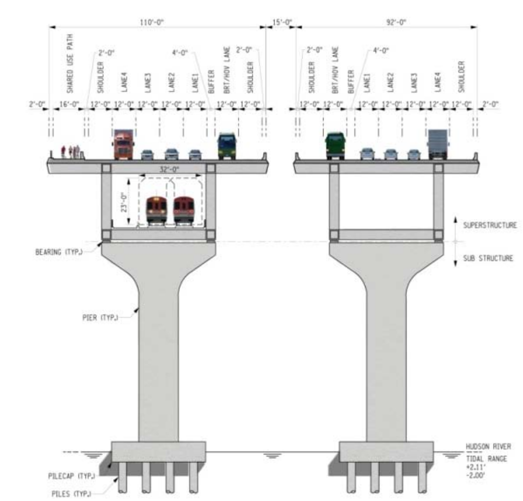
Engineering	Transportation	Environmental		Cost
		Construction	Operation	
Structural Integrity	Roadway Congestion	Displacement Acquisitions	Land Use	Capital Cost* (Full Build, cable stayed bridge)
Operations and Risk	Alternative Modes	Historic Resources	Displacement Acquisitions	Operating and Maintenance Cost
Seismic	Mode Split	Archeological Resources	Historic Resources	Life Cycle Costs
Redundancy	Transit Ridership	Parkland 4(f)	Archeological Resources	
Emergency Response	Non-Vehicular Travel	River Ecology	Parkland 4(f)	
Navigation	Reserve Capacity	Community Noise	River Ecology	
Life Span	Transportation System Integration		Avifauna	
Construction			Visual	

*Interchange 10 to Interchange 9

Table ES 1 - Bridge Evaluation Criteria (shaded criteria were not utilized)



Single Level Option 3



Dual Level Option 5

Figure ES 1- Tappan Zee Bridge Replacement Options Recommended for Inclusion in the DEIS

Benefits and drawbacks of the RTZB options

The RTZB options have to address three functional requirements.

1. They need to deliver CRT to a lower level than the highway lanes at both the Rockland and Westchester landings.
2. During construction, the north structure will have to carry all the traffic while a portion of the existing TZB is removed to make the tie-ins from the landings to the south structure.
3. There are advantages for an option to be able to phase or defer the construction of the CRT transit elements until after the Tier 2 Transit environmental process is completed and funding is secured.

The tiering process, described further in Section 1.1, enables the project to reach separate and earlier environmental process determinations for elements of the project, in this case, replacement of the TZB, and construction of the highway elements. Subsequent environmental determinations will enable provision of the CRT and BRT transit modes. Recognizing the phased future inclusion of transit elements, the RTZB and highway elements provide for transit accommodation and are designed to be "transit ready."

Single Level Crossings

The single and dual-level crossing options are depicted in Figure 1.5 on page 5 in the body of the report

Option 1 is an intuitive arrangement of the transportation modes in a balanced, mirror-like arrangement with highest speeds, capacities and loads arranged from the center out. The integrated, symmetrical and balanced main span is efficient. The deep foundations require construction of the CRT piles, pile caps and columns at the same time the highway/BRT structures are constructed, leaving a visual reminder until the CRT is built. Construction of the deck that carries only CRT could be postponed for both the approach and main spans and can be constructed without additional dredging, principally from the previously built highway decks. Postponing the construction of the CRT tunnel portal in Rockland, located between the highway lanes, results in difficult, and therefore expensive, construction because of limited space, but is possible.

Option 2 locates CRT on the side, which makes it easier to build later, but loses the savings that come from integrating the support structure through the Main Span. This integration is not possible due to the torque on the structural systems created by the heavy rail loads. As a result, the CRT is isolated from the rest of the RTZB leading to higher total costs and concerns about emergency access. If construction of CRT is phased, there are two options for how its construction can be accomplished – minimize initial CRT construction or minimize total dredging and construct the CRT substructure concurrently. Minimizing construction of the CRT elements necessitates an additional 0.90 million cubic yards (mcy) of dredging in the future. At the Rockland landing, the south side CRT tunnel portal will require deep open-cut construction in the hillside and the acquisition of 14 residences. Access to construct the portal will be easier than Option 1, but the construction itself will be more difficult.

Option 3 has the same deck cross section as Option 1 but has been designed to support CRT construction on a crosshead beam between the two highway columns. The Main Span is fundamentally the same as Option 1. The fewer columns reduce visual presence, environmental impacts, schedule and costs. Option 3 provides a way to add the CRT later with the minimum of initial construction, yet keeps it in the preferred center location for symmetry. The two-column piers would be designed for the eventual CRT loads. When funding is available, CRT could be added without additional dredging from the already-constructed highway/BRT deck by adding the crosshead beams, bringing in a gantry, and installing the CRT deck. Most materials and components could be delivered from the adjacent highway decks.

For a single-level crossing, Option 3 with 33% fewer columns in the river resulting in fewer environmental impacts and lower cost and duration is preferred over Options 1 and 2. Construction of the CRT is more efficiently phased without additional river dredging. The Main and Approach spans are symmetrical and allow continuous direct emergency access for CRT.

Dual Level Crossings

Option 4 is a variation of Option 3. The highway decks are adjacent with CRT below on the lower level making it a dual-level option. Bringing the highway decks together over the CRT results in a number of operational and structural challenges. Across the Main Span, the CRT deck would be integrated with the other two decks to form a single deck. Structurally, this is undesirable and introduces a lack of redundancy. This massive deck, when added to the very deep cross section results in a "heavy," visually unappealing, crossing. Operationally it is difficult to inspect the structure, leaves the CRT susceptible to high winds and emergency access to the CRT is indirect. Lacking the structural efficiency of a truss, its pier spacings are closer, its structural form is more massive and thus requires 49% more piles than the other dual-level options.

Options 5 and 6 are the traditional way to carry rail and highway over a river. The deep truss sections enable economy in structural form, longer spans and fewer expensive sub-structure elements. With CRT below, the overall cross section is narrower reducing impacts at the Rockland landing. Visually, the cross section is deeper than the single-level options, but is consistent across the length of the crossing. These options are simpler to build because entire truss sections can be economically pre-constructed elsewhere then floated in and lifted into position. There is little to postpone in the construction for the CRT elements as only installation of the CRT deck and rail infrastructure can be phased.

Option 5 puts all the rubber-tire vehicles on the same level and provides the most flexibility, whether managing major incidents or anticipating long term changes in mobility, to adapt the wider available deck surface to necessary demands.

Option 6 is the most spatially efficient using both lower bays to carry transit. The location of BRT on the lower level, however, introduces vulnerabilities to the structure.

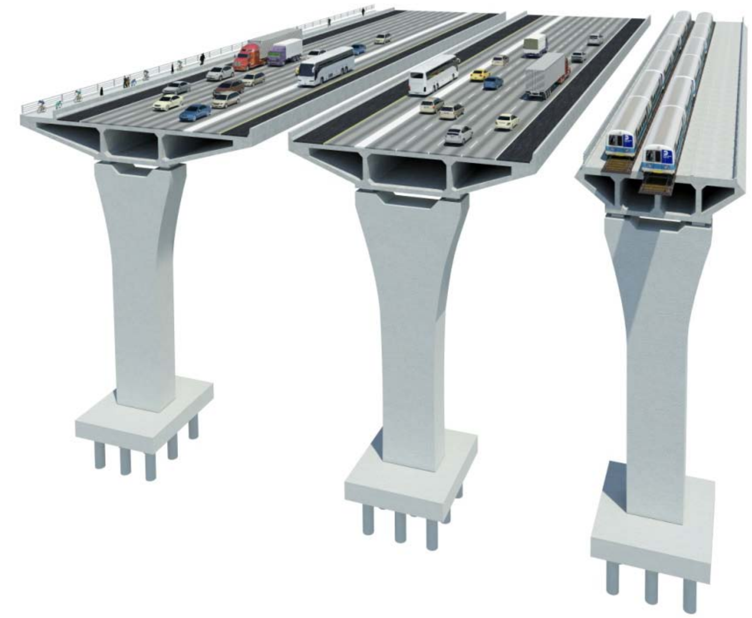
Of the dual-level options, Option 4 is the least preferred. Options 5 and 6 can be compared on the basis of flexibility in operations and security, where Option 5 is preferred in both areas. The five lane deck of Option 5 provides for BRT to operate as either a Busway or in an HOV/HOT lane. The width improves the ability to access emergency events and to manage incidents more efficiently. With limited access to the structural systems under the deck and the preclusion of vehicle-based threats thereunder, security of the crossing is vastly better than Option 6.

Report Conclusions

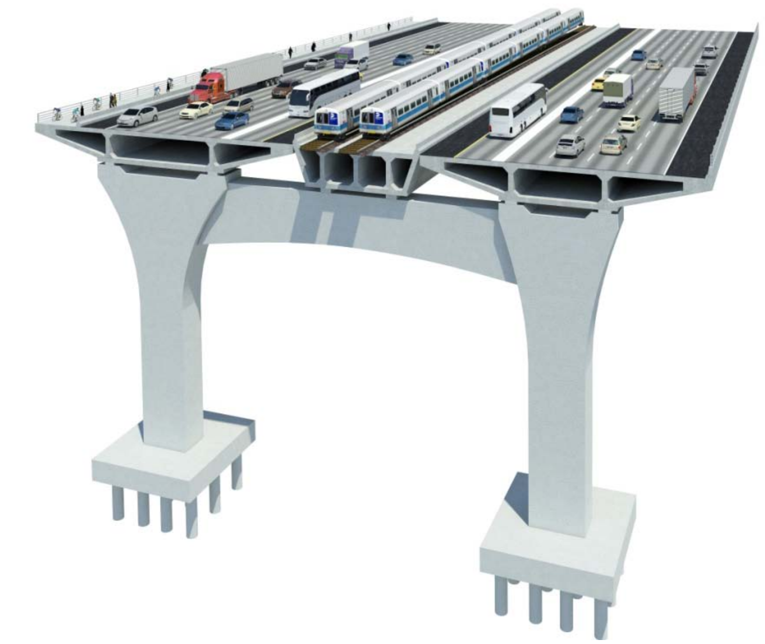
This report concludes that Replacement Tappan Zee Bridge Single Level Option 3 and Dual Level Option 5 be evaluated in the *EIS* with the remaining options eliminated from further consideration. (Figure ES1)

- Single Level Option 3 is recommended over the other two single-level options because of its reduced number of columns and lesser foundation requirements with associated reduction in hydro-acoustic and suspended sediment impacts, construction duration, noise and construction cost, as well as its efficient structural arrangement in the Approach and Main Span structures leading to superior visual transparency, and its narrower footprint at the landings leading to fewer acquisitions and displacements and fewer impacts to historic architectural resources.
- Dual Level Option 5 is recommended over the other dual-level options because it principally avoids the pitfalls of the other two options. It, unlike Option 4, has vastly simpler and redundant Main Span structures, fewer piles and piers and thus greatly reduced in-river, community noise and visual impacts, along with a year shorter construction schedule. It has decks that can be replaced, is easy to inspect, and its CRT is less susceptible to wind and better contained during a derailment. Unlike Option 6, however, it supports greater flexibility in highway operations, has a larger reserve capacity, is less susceptible to intentional risks and can temporarily support all 8 lanes of traffic on the north structure during construction.

Option 1 – Single Level CRT Center Three Structures
Two highway/BRT (HOV/HOT or Busway) structures with a central CRT structure



Option 2 – Single Level CRT Center Three Structures
Two highway/BRT (HOV/HOT or Busway) structures with a CRT structure to the south



Option 3 – Single Level CRT Center Two Structures
Two highway/BRT (HOV/HOT or Busway) structures with a central CRT on added supporting crossbeam

Option 4 – Dual-Level CRT Center Stacked Option One Structure
Two highway/BRT (HOV/HOT or Busway) decks above a central CRT deck on a composite single structure

Option 5 – Dual- Level CRT North Two Structures
Two Dual-level structures with highway/BRT (HOV/HOT or Busway) decks above an CRT below on the North

Option 6 – Dual-Level Transit Below Two Structures
Two Dual-level structures with highway above and CRT below on the North and BRT Busway below on the South

Figure ES 2- Replacement Tappan Zee Bridge Options

Key Single Level Differences

In Options 1 and 3, CRT is located between the highway/BRT decks, while Option 2 locates it south of the highway/BRT decks. Option 3 also uses 2 lines of columns instead of 3 to support the same superstructure. These two key differences lead to a number of other significant differences between the single-level options.

Engineering

1. The heavy loads of CRT would be centrally located for Options 1 and 3, leading to a **symmetrical and unified Main Span**. Option 2 would require an independent CRT Main Span structure.
2. The reduced level of effort for Option 3 results in a **6 month schedule reduction** of the 5 ½ year Initial Build schedule for Options 1 and 2.
3. While **emergency turnarounds on the RTZB** can be provided for all three options and maintenance turnarounds will be provided at both ends of the bridge, those of Option 2 would **not need to cross the CRT tracks** (requiring temporary suspension of CRT service), and thus would be more available for Thruway personnel, NYSP and first responder use. As Metro-North has indicated that suspension of CRT service can be accommodated during major emergencies, the significance of this differentiator is diminished.
4. The 15-foot separation of the highway/BRT decks from the CRT deck in Options 1 and 2 (100-foot separation in Option 2 if CRT is fully phased), would require bridging at regular intervals to provide walk-in access for emergency responders to a major CRT event (i.e., fire, derailment, etc.). As the CRT is continuously adjacent to both highway/BRT decks in Option 3, **more frequent and direct emergency response access to the CRT** is possible.
5. Access to **Main Span cables for inspection and repair has been identified as an easier** undertaking for Options 1 and 3. Option 2 would likely require closure of one CRT track to effectively and safely undertake inspections and repairs.
6. The central location of CRT in Options 1 and 3 is anticipated to result in **fewer occasions for suspension of CRT service** and reduced measures to ensure Main Span stability **during sustained high speed wind events.**

Environmental

7. At the Rockland landing, the narrower width of Option 3, and the ability of Option 2 (minimum dredging) to connect its CRT maintenance road to River Road before reaching shore, result in **less acquisition and fewer displacements** than Option 1 and significantly fewer impacts than Option 2 (minimum CRT), the widest of the single-level options.
8. Option 3 has been identified as requiring **fewer displacements of historic architectural resources**.
9. Options 1 and 3 have the **least potential to affect archaeological resources**, followed by Option 2 (minimum dredge). Option 2 (minimum CRT) has the greatest potential to affect archaeological resources.
10. Option 3 has substantially fewer columns in the river (112) than Options 1 and 2 (168) While this reduces its permanent loss of habitat (not a significant differentiator), Options 1 and 2 **provide more new in-river habitat** (6.4 to 6.6 acres along the faces of its pile caps) than Option 3 (4.6 acres).
11. With **11-13% fewer piles** than for Options 1 and 2, Option 3 provides for **a significant reduction in the amount of underwater acoustic impacts to aquatic resources** during pile driving.
12. During the Final Build, CRT segments for all three options would be assembled using gantry methods. For Options 1 and 3, segment delivery would be from reconfigured adjoining highway lanes. If the substructure for Option 2 is pre-constructed (minimum dredge), segment delivery would also be from adjoining highway lanes; however, Rockland shore access, and thus dredging, will still be required to construct the CRT Main Span. If CRT in Option 2 is fully phased (minimum CRT), all construction delivery would be from the water, requiring a full second dredge. Option1 and Option 3 would **not require the second round of dredging** and thus have **reduced levels of suspended sediment loading** compared to either version of Option 2 (minimum dredge or minimum CRT).
13. The smaller dredging footprint of Option 3 also **reduces the extent of temporary loss of habitat.**
14. The 6 month **shorter construction duration** of Option 3 **reduces the level of construction impacts** upon the surrounding communities and motoring public.
15. Evaluation of the visual effect of the three single-level options identifies the **greater visual transparency** of the 2-column support of Option 3 would be more favorably received than the 3-column substructure of Options 1 and 2.
16. Tied both to the amount of pile driving and the duration of construction , **construction noise affecting the community would be substantially less** for Option 3.

Cost

17. The pre-constructed columns of Options 1 and Option 2 (minimum dredge) will remain unused until the CRT is completed. Between Initial Build and Final Build, Option 2 (minimum CRT) and Option 3 present le**ss unused infrastructure** than Option 1 and Option 2 (minimum dredge).
18. With CRT in the center for Options 1 and 3, the Main Span would be supported by 8 towers. The separate CRT Main Span structure required for Option 2, would enable a 6-tower Highway/BRT Main Span; however, the 4 towers required for the CRT Main Span results in Options 1 and 3 **requiring fewer Main Span towers**. The reduction in towers has consequential effects on maintenance, cost, schedule, number of piles and thus in-river impacts.
19. To complete the CRT, Option 3 will have similar costs (in 2025 dollars) as Option 1 ($1.93b vs. $1.85b) and **substantially lower costs to complete CRT** than Option 2, whether constructed with minimum dredging undertaken ($3.14b) or minimum CRT infrastructure initially constructed ($4.15b).
20. Options 1 and 3 require **substantially less work to complete the CRT elements of the Main Span** during Final Build than Option 2. Options 1 and 3 would only require infill transverse beams between the Main Span structures and placement of CRT deck, which could be accomplished from the adjoining highway/BRT lanes. Option 2 would require a full re-mobilization, including dredging, in-water pile driving, support facilities and all trades necessary to construct the remaining CRT foundations, and the entire CRT Main Span.
21. The Initial Build costs (in 2012 dollars for a 2015 midpoint of construction) for Options 1, 2 (minimum dredge) and 3 are similar at $6.5 to $6.7 billion. Option 2 (minimum CRT) has a 10% **lower initial cost** at $6.0 billion. This option, however, does have the greatest total cost.
22. The schedule reduction and the reduced material quantities result in an Option 3 phased construction **Total Cost savings** of $1.26b over Option 1 and $1.75b over Option 2.

	Issue	Criteria	1	2 - Min CRT	2 - Min Dredge	3
	Engineering					
1	Symmetrical and unified Main Span	Structural Integrity	✓			✓
2	Reduced Schedule	Construction Impacts	✓			✓
3	Non-CRT crossing Emergency Turnarounds	Emergency Response		✓	✓	
4	Better Emergency Response access to CRT	Emergency Response				✓
5	Easier Main Span Cable inspection and repair	Operations and Risk	✓			✓
6	Fewer wind caused CRT suspensions	Operations and Risk	✓			✓
	Environmental					
7	Fewer acquisitions and displacements	Displacements and Acquisitions			✓	✓
8	Fewer displacements of Historic Resources	Historic Resources				✓
9	Least potential to affect archaeological resources	Archaeological Resources	✓			✓
10	Greater in-river habitat	Ecosystems and Water Resources				✓
11	Reduced underwater acoustic impacts	Ecosystems and Water Resources				✓
12	Reduced suspended sediment loading	Ecosystems and Water Resources	✓			✓
13	Reduced temporary loss of habitat	Ecosystems and Water Resources				✓
14	Reduced construction duration	Ecosystems and Water Resources				
15	Greater visual transparency	Visual				✓
16	Reduced construction noise	Community Noise				✓
	Cost					
17	Less Unused Initial infrastructure	Capital Cost		✓		✓
18	Fewer Main Span Towers	Capital Cost	✓			✓
19	Lower Cost to complete CRT	Capital Cost	✓			✓
20	Less effort to complete CRT elements of Main Span	Capital Cost	✓			✓
21	Lower Initial Cost	Capital Cost		✓		
22	Lower Total Cost	Capital Cost				✓

Table ES 2 - Summary of Single Level Differences

Key Dual Level Differences

Casual inspection identifies that Option 4 is quite different from Options 5 and 6, which in structural form are practically identical. Option 4 is more akin to single-level Option 3. Dual Level Options 5 and 6 have similar structural forms but Option 6 has smaller highway decks since BRT is relocated to the lower bay.

Engineering

1. The over-under arrangement of Option 4 makes it impossible to include central pylons or arches for the Main Span, thus the approach cross section must transition to a single composite structure supported by four pylons or arches outside of the decks. This would require exceptionally strengthened pylons or arches to support the massive composite structural deck. Options 5 and 6 avoid this level of strengthening and complexity by employing six pylons or arches to support **simple Main Span structures** over two adjacent spans.
2. The reduced number of piles and piers and the simpler erection methods of the truss structures **reduce the Initial Build schedule** to construct Options 5 and 6 by 1½ years compared to Option 4.
3. The width of the north span of Option 6 is only 94 feet. During construction, when all traffic is diverted to the north structure, this limited width would be able to only support a 7-lane operation employing a movable barrier, if standard 12-foot lanes are used. If substandard 11-foot lanes are used, an 8-lane fixed barrier operation could be employed. At 110 feet across, the north structures of Options 4 and 5 **support a full 12-foot wide, 8-lane fixed barrier operation during the temporary condition**.
4. The box girder form of the Option 4 highway decks is limited in its ability to effect a full deck replacement, potentially limiting the life span of the superstructure. Options 5 and 6 support the **ability to fully replace the roadway deck**.
5. In Option 4, because of the close proximity of the highway deck structures, access for standard inspection equipment would be difficult. As an under-bridge inspection unit (UBIU) would not be able to reach under the full width of the bridge, special inspection gantries would need to be utilized. In Options 5 and 6, **easier access for inspection** would be provided on the lower level without any interruption of traffic or temporary lane or shoulder closures on the highway above, but may require the temporary suspension of CRT.
6. All the dual-level options have CRT on the lower level with the same potential accidental and intention risks associated with fire, impact and explosion. Options 4 and 5 have **reduced risks**, compared to Option 6**,** associated with similar (though possibly much more impactful) events in the BRT lanes on the lower level due to the potential to access these lanes by large vehicles. These risks, particularly those associated with Intentional Events are considered significant with the potential for major damage.
7. The location of CRT within the structural trusses of Options 5 and 6 may, compared to Option 4, **result in fewer occasions for suspension of CRT service due to sustained high wind events**. The over-under arrangement of Option 4 may result in eddies and increased wind forces upon the CRT.
8. The location of CRT within the structural trusses of Options 5 and 6 may also, compared to Option 4, **reduce the risk of CRT leaving the structure during an extreme derailment**.
9. Option 4 and 5 **maximize the flexibility of highway operations in the event of vehicle accidents**. Should a significant accident occur, traffic would be diverted around the incident if possible. The larger width of Option 5 due to its inclusion of the BRT lane on its upper level would provide greater space for traffic to be diverted than would be available for Option 6. Diversion on to the Busway below would not be desirable as the access and egress points to the Busway at each landing could not accommodate major traffic volumes or would channel traffic through the possible BRT station at the Tarrytown landing.

Transportation

10. Options 4 and 5 **maximize the operational flexibility of the vehicular transport system in the corridor** as it accommodates BRT in either a Busway or in HOV/HOT lanes, and places these lanes together with the general purpose highway lanes. Having these lanes together provides the most flexibility, whether managing major incidents or anticipating long term changes in mobility, to adapt the wider available deck surface to necessary demands.
11. Likewise Options 4 and 5 with their larger decks, provide a **larger degree of reserve capacity** that can be practically employed than can be developed with the busway system and narrower decks of Option 6.
12. Options 4 and 5 support the both the BRT HOV/HOT and the Busway alternatives. Option 6 does not support the BRT HOV/HOT Alternative.

Environmental

13. Based upon indirect visual impacts, Option 6, closely followed by Option 5 would have the **least potential to adversely impact historic architectural resources**.
14. With BRT on the lower level and thus narrower decks, Option 6 **results in less shading of the river** (16-19%) than Options 4 and 5.
15. Similarly, Option 6 results in less impervious surface (16-19%) and thus **reduced stormwater management requirements** than Options 4 and 5.
16. The greater number (112) of in-river piers of Option 4 results in a **greater quantity of vertical in-river habitat** (38%) upon the faces of the pier caps, compared with the fewer number (64)of piers of Options 5 and 6.
17. Option 4 with its closer pier spacing, and heavier dead load requires 49% more piles than Options 5 & 6. As a result, Options 5 & 6 have substantially **reduced underwater acoustic impacts**, both in quantity and duration.
18. The construction techniques to erect Option 4 require a smaller dredged access channel and thus result in **lower levels of suspended sediment loading** compared to Option 5 (13%) and Option 6 (7%).
19. The smaller dredged access channel of Option 4 also results in similar **reduction in temporary loss of habitat** compared to Option 5 (13%) and Option 6 (7%).
20. The 12 month shorter construction duration of Options 5 and 6 **reduces the level of construction impacts** upon the surrounding communities and motoring public.
21. Evaluation of the visual effect of the three dual-level options identifies the fewer number of piers and **reduced visual presence of the superstructure** of Options 5 and 6 would be more favorably received than the more massive and deeper superstructure of Option 4.
22. With significantly less pile driving and shorter construction schedule by a year, **construction noise affecting the surrounding communities would be substantially less** for Options 5 and 6.

Cost

1. The Initial Build Capital cost (in 2012 dollars for a 2015 midpoint of construction) for the RTZB for Dual Level Options 4, 5 and 6 are very similar at $7.27, $7.60, and $7.46 billion, respectively. These costs are reported in 2012 dollars and include contingency, escalation and soft costs. The Final Build Capital costs to add the CRT (and for Option 6 the BRT busway) are $1.750 billion, $808 million, and $1.385 billion for the respective Dual Level Options. These costs are in 2027 dollars. Summing these, while recognizing the difference in years spent, leads to a Total Capital cost of $9.02, $8.41, and $ 8.85 billion for Dual Level Options 4, 5 and 6. The **lower Total Capital cost** for Option 5 is principally due to the lower cost to complete the Final Build transit elements, consisting only of CRT.

	Issue	Criteria	4	5	6
	Engineering				
1	Simple Main Span Structures	Structural Integrity		✓	✓
2	Reduced Initial Build Schedule	Construction Impacts		✓	✓
3	8 12-foot lanes on North Structure during construction	Construction Impacts		✓	✓
4	Better ability to replace Highway deck	Operations and Risk		✓	✓
5	Easier access for inspection	Operations and Risk	✓	✓	✓
6	Reduced risks from intentional events	Operations and Risk	✓	✓	
7	Fewer wind caused CRT suspensions	Operations and Risk		✓	✓
8	Reduced risk of CRT leaving the structure	Operations and Risk		✓	✓
9	Maximum flexibility of highway operations during vehicle accidents	Operations and Risk	✓	✓	
	Transportation				
10	Maximum system flexibility	Reserve capacity	✓	✓	
11	Larger reserve capacity	Reserve capacity	✓	✓	
12	Supports both the BRT HOV/HOT alternative and the BRT Buslane alternative	Transportation System Integration	✓	✓	
	Environmental				
13	Least potential indirect visual impact to Historic Resources	Historic Resources		✓	✓
14	Less shading of the river	Ecosystems and Water Resources			✓
15	Reduced stormwater management requirements	Ecosystems and Water Resources			✓
16	Greater in-river habitat	Ecosystems and Water Resources	✓		
17	Reduced underwater acoustic impacts	Ecosystems and Water Resources		✓	✓
18	Reduced suspended sediment loading	Ecosystems and Water Resources	✓		
19	Reduced temporary loss of habitat	Ecosystems and Water Resources	✓		
20	Reduced construction duration	Ecosystems and Water Resources		✓	✓
21	Reduced visual presence	Visual		✓	✓
22	Reduced construction noise	Community Noise		✓	✓
	Cost				
23	Lower Total Cost	Capital Cost		✓	

Table ES 3 - Summary of Dual Level Differences

Contents

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Acronyms and Abbreviations

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
AREMA	American Railway Engineering and Maintenance of Way Association
BM	*Bridge Manual* (design)
BODR	*Bridge Options Definition Report*
BRT	Bus Rapid Transit
BSC	Bridge Station Connector
CRT	Commuter Rail Transit
CFR	*Code of Federal Regulations*
DEIS	*Draft Environmental Impact Statement*
EB	Eastbound
EIS	*Environmental Impact Statement*
EMU	Electro-Motive Unit (electric rail car)
ES	Executive Summary
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GRL	Gross Rail Load
HARS	Historic Areas Remediation Site
HDM	*Highway Design Manual*
HIR	*Highway Improvement Report*
HLC	Hudson Line Connector
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
LRFD	Load-and-Resistance Factor Design
mcy	million cubic yards
MNR	Metro-North Railroad
mph	miles per hour
MTA	Metropolitan Transportation Authority
NAVD88	North American Vertical Datum of 1988
NEPA	*National Environmental Policy Act*
NFPA	National Fire Protection Association
NHL	National Historic Landmark
NRE	National Register eligible
NRL	National Register Listed
NY	New York
NYCRR	*New York State Codes, Rules and Regulations*
NYS	New York State
NYSM	New York State Museum
NYSP	New York State Police
NYSTA	New York State Thruway Authority
R&R	Rehabilitation and Replacement Report (*Alternatives Analysis for the Rehabilitation and Replacement of the Tappan Zee Bridge)*
RNRE	Recommended National Resource Eligible
ROW	Right-of-Way
RTZB	Replacement Tappan Zee Bridge
SAWG	Stakeholders Advisory Working Group
SOV	Single-Occupant Vehicle
SSR	*Scoping Summary Report*
SUP	Shared-use Path
TAOR	*Transit Alignment Options Report*
TBD	To be determined
TBM	Tunnel Boring Machine
tcy	thousand cubic yards
TMSR	*Transit Mode Selection Report*
TOD	Transit Oriented Development
TP	Technical Paper
TSDM	*New York State Thruway Authority Structure Design Manual*
TTC	Tarrytown Connector
TZB	Tappan Zee Bridge (existing bridge)
UBIU	Under-Bridge Inspection Unit
WB	Westbound

Abbreviations

e.g.	*exempli gratia* (for example)
ft.	foot/feet
i.e.	*id est* (that is)
lbs	pounds (weight)
no.	number
Req.	Requirement

1 Introduction

1.1 Project Overview

The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) – co-lead agencies, the New York State Department of Transportation (NYSDOT), the New York State Thruway Authority (NYSTA), and MTA/Metro-North Railroad (MNR), a subsidiary of the Metropolitan Transportation Authority (MTA) – the Project Sponsors, are preparing an *Environmental Impact Statement for the Tappan Zee Bridge (TZB)/I-287 Corridor Project* in Rockland and Westchester Counties, New York (NY).

The I-287 Corridor extends 30 miles between the Village of Suffern in Rockland County and the Village of Port Chester in Westchester County. The counties are linked by the Tappan Zee Bridge (TZB) over the Hudson River.

One of the key steps in preparation of the *Draft Environmental Impact Statement (DEIS*) is the development and refinement of the EIS alternatives. As this project has transit, bridge, and highway elements, the process of defining these elements of the EIS alternatives is documented in a number of studies by the Project Sponsors:

- *Transit Alignment Options Report* (*TAOR*)
- *Highway Improvements Report* (*HIR*)
- *Bridge Options Development Report* (*BODR*) and its successor *Feasible Alternatives for the Replacement Tappan Zee Bridge* (*TP 9*, this report).

This process is represented in Figure 1, which shows the parallel development of the three highway, bridge and transit studies leading to the development of the EIS alternatives. Early in the process, project scoping provided a forum for the public to provide comments and feedback on the Project Purpose and Need, potential alternatives, and environmental analysis being considered in the *EIS*. Scoping was closed in Spring 2009.

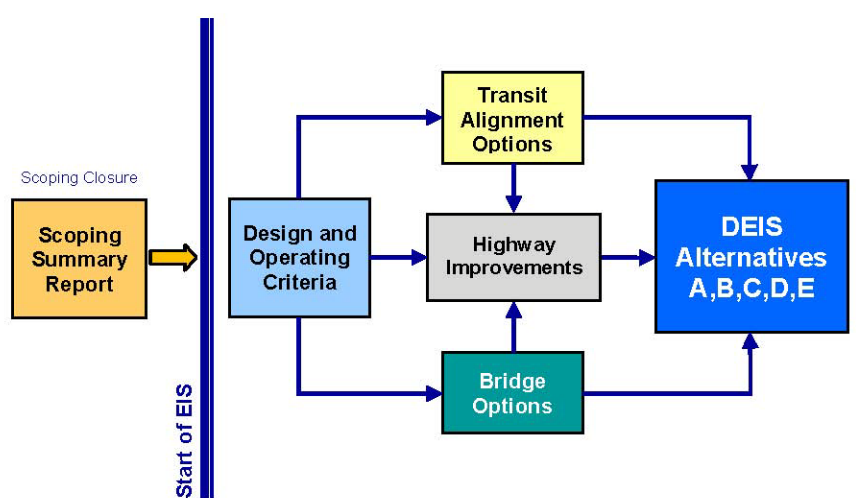


Figure 1.1 - Alternatives Development Process

Project Purpose and Need

The Purpose and Need for the Tappan Zee Bridge/I-287 Corridor Project builds on the problems and deficiencies in the corridor, and states the basis for identifying and selecting solutions to effectively and efficiently address those needs, while respecting the natural and human environment.

On February 14, 2008, a revised *Notice of Intent* for the project was published in the *Federal Register* (Vol. 73 No. 31) which stated:

"The purpose and need of the project is to address the transportation safety, mobility and capacity needs of the Tappan Zee Bridge/I-287 Corridor."

It specifically identified that:

". . ., the *EIS* will evaluate alternatives that address the following needs of the Corridor:

- Preserve the existing river crossing as a vital link in the regional and national transportation network
- Provide a river crossing that has structural integrity, meets current design criteria and standards, and accommodates transit
- Improve highway safety, mobility and capacity throughout the Corridor
- Improve transit mobility and capacity throughout the Corridor and travel connections to the existing north-south and east-west transit network"

Based upon these project purposes and needs, the *Scoping Summary Report* (*SSR*, May 2009) identified five Goals "to address the bridge, highway and transit needs of the corridor:

- Improve the mobility of people, goods and services for travel markets served by the Tappan Zee/I-287 corridor
- Maximize the flexibility and adaptability of new transportation infrastructure to accommodate changing long term demand
- Maintain and preserve vital elements of the transportation infrastructure
- Improve the safety and security of the transportation system
- Avoid, minimize and/or mitigate any significant adverse environmental impacts caused by feasible and prudent corridor improvements"

The project goals and objectives were developed to indicate how the project will satisfy the Purpose and Need. Objectives are used to measure progress in the attainment of goals. Project alternatives developed to respond to the Purpose and Need are evaluated by how well they meet the goals (e.g., Improve Mobility) by determining their likely performance against various objectives (e.g., reduce traffic congestion, improve travel times, etc.). All levels of evaluation conducted throughout the development of the *EIS* will be consistent with the Purpose and Need and the project's goals and objectives.

Project Alternatives

The scoping process explores a broad range of alternatives and options – then evaluates them to reduce the number considered in the environmental process. The evaluation process identifies and eliminates those that fail to meet the project purpose and needs and selects those for further consideration that best meet the project's purpose and needs and goals and objectives.

Transit mode alternatives for the I-287 corridor were identified and evaluated in the *Transit Mode Selection Report (TMSR,* May 2009*).* The basic question of whether the Tappan Zee Bridge should be rehabilitated or replaced was addressed in the *Alternatives Analysis for Rehabilitation and Replacement of the Tappan Zee Bridge (R&R Report*, March 2009*).* At the conclusion of the Scoping process, the alternatives analysis documented in the *R&R Report* determined that full replacement was the only reasonable option for the TZB.

The results of these two reports, summarized in the *SSR*, are a set of five transit alternatives with a common replacement Tappan Zee Bridge (RTZB) element for evaluation in the *DEIS*:

- Alternative A – No build
- Alternative B – Full-Corridor Busway and Rockland CRT
- Alternative C – Busway in Rockland/Bus Lanes in Westchester and Rockland CRT
- Alternative D – BRT in HOV/HOT Lanes in Rockland/Busway in Westchester and Rockland CRT
- Alternative E – BRT in HOV/HOT Lanes in Rockland/Bus Lanes in Westchester and Rockland CRT

These broadly defined project alternatives form the basis of a planning level vision for a fully integrated transit and highway system along the I-287 corridor starting in Rockland County, continuing across the Tappan Zee Bridge with the CRT connecting to the Hudson Line and the BRT continuing across Westchester County, fulfilling the project's Purpose and Need.

Tiering and Construction Phasing

The revised *Notice of Intent* also announced the Project Sponsors decision to prepare the *National Environmental Policy Act* (*NEPA*) documentation for this project using a tiered analysis approach. Tiering is a permitted method for developing environmental impact analyses for complex, large transportation projects pursuant to 23CFR 771.111(g). With this approach, the project will be able to expedite the delivery of integrated, multimodal transportation improvements in a way that allows each modal element to advance at its own pace.

The project's tiered environmental process includes a concurrent Tier 1 transit analysis and Tier 2 bridge and highway analysis. The Tier 1 transit analysis will define and assess the mode choices, alignments, and general locations of stations, termini, and facilities resulting in selection of one of the project's five transit alternatives. The Tier 2 bridge and highway analysis will focus on selection of an RTZB configuration and inclusion of various highway improvements along the corridor. This analysis will incorporate modifications to the highway elements consistent with decisions made as part of the Tier 1 transit analysis.

At the conclusion of this initial environmental process, approved Tier 2 elements can be constructed during an "initial build" construction phase, with accommodation provided for approved Tier 1 elements. To avoid disruptions or to minimize costs, construction and/or accommodation of some transit elements identified in the Tier 1 transit analysis may be warranted when the bridge is replaced and highway improvements are made during the "initial build" construction phase.

Subsequent Tier 2 transit analyses will define and evaluate supporting elements of the transit system such as stations and access for the selected alternative. Optional means of modifying the existing corridor elements to accommodate the future provision of transit have been evaluated and documented in the *Transit Alignment Options Report* (*TAOR*) for each of the project's transit alternatives. Upon the conclusion of the subsequent Tier 2 transit analyses, the project's transit elements can be constructed during a "final" build construction phase to provide an integrated transit and highway system.

Because the phased construction will provide the transit elements after the TZB has been replaced and the highway improvements have been made, it is necessary to define not just what the complete "full build" system will entail, but also what would be constructed during the "initial build" and "final build" construction phases.

1.2 RTZB Selection Methodology

Overview

The *SSR* stated that two configurations for the replacement of the Tappan Zee Bridge would be evaluated in the *DEIS* – Dual Level and Single Level. The process of selecting preferred options for the RTZB for evaluation in the *DEIS* began with the issuance of the revised *Notice of Intent.* This led to the drafting in January 2009 of the *Tappan Zee Bridge Replacement DEIS Work Plan* (*Work Plan*, finalized May 2009). The plan identified a three step process. Step 1 concluded with the identification of 6 suitable options to replace the TZB. This report is the second step and identifies the options to be evaluated in the *DEIS*. Step 3 is the identification of the preferred RTZB alternative through the Environmental Process.

Step 1 – Identifying Possible Options

Step 1 defined the RTZB Options. Focused on engineering aspects, and recognizing there are many possible alignments, cross-section arrangements, physical forms and methods of construction, this first step primarily used engineering principles to identify practical, reasonable and prudent solutions. To achieve this, the variation in alignments, landing configurations, construction procedures, schedule and phasing, operations, section arrangements, foundations, span lengths & cost, bridge types and demolition were considered.

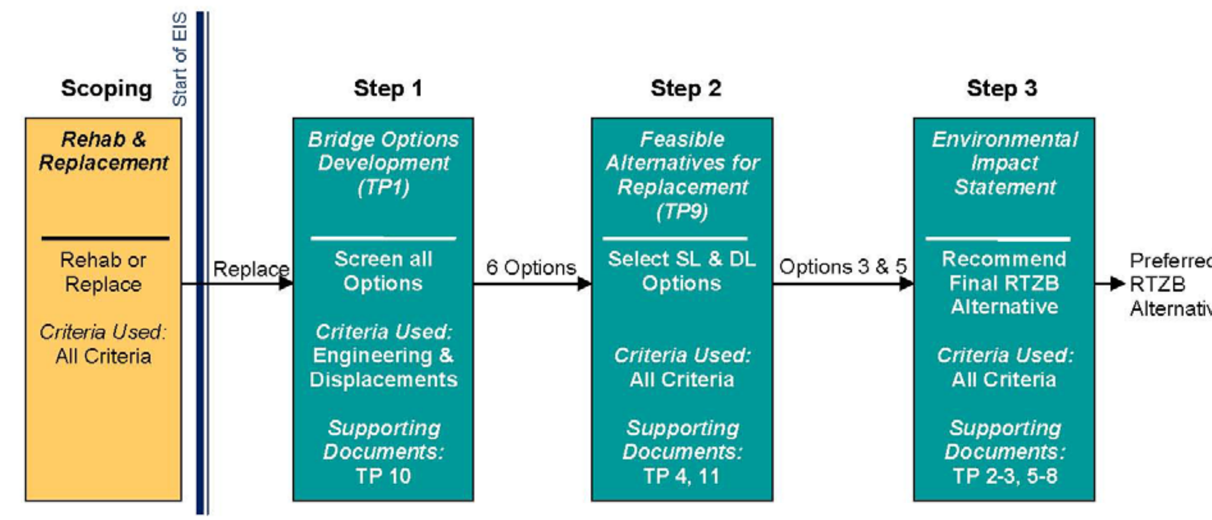


Figure 1.2 - Bridge Options Development Process

To identify whether the CRT connection to the Hudson Line was a factor in the selection of possible bridge configurations, the following technical paper (TP) was developed:

- *TP 10 Tunnel and Trestle Report*

In considering elements that might define or constrain the available options, it was initially thought the CRT connection from the RTZB to the Hudson Line might limit certain bridge configurations. At this juncture, the *Tunnel and Trestle Report* (*TP 10*) has determined that the choice of CRT alignment will not preclude any of the possible bridge configurations.

The bridge cross-sectional forms considered in Step 1 began with the two representative forms (Options 1 and 5) that were employed in preparing the *R&R Report*. In identifying feasible RTZB cross sectional configuration options, the *BODR* incorporated a global review of possible bridge forms, input from the members of the Bridge Stakeholders Advisory Working Group (Bridge SAWG), and a geometric assessment of possible arrangements of the BRT, CRT and highway modes. Evaluated in light of engineering, operating and limited environmental criteria, the numerous RTZB options identified were screened down to six reasonable RTZB cross-sectional configuration options that satisfied nine specific engineering-based requirements.

The conclusions of this Step 1 process to identify and screen practical solutions were documented in:

- *TP 1 Bridge Options Development Report (BODR).*

Step 2 – Identifying Feasible Alternatives for the RTZB

The next step documented the process by which the "practical, reasonable and prudent" configuration options identified in Step 1 were evaluated against the entire set of bridge evaluation criteria listed in Table 1. Its intent was to narrow the list of alternatives to be analyzed in the *DEIS*, but not to exclude any environmentally preferable alternative. The conclusions reached during this step have been documented in this report:

- *TP 9 Feasible Alternatives for the Replacement Tappan Zee Bridge (TP 9)*.

During this step, more was learned about the options recommended in the *BODR*. Characteristics about their foundations, costs, structural systems, appropriate Main Span types, construction and visual impact were identified. To understand specific issues needed to further develop the BODR options, the following technical papers were developed:

- *TP 4 Possible Bridge Types for the RTZB*
- *TP 11 Shared Use Path Report*

Designs were further developed enabling determination of their costs and environmental impacts. Additional engineering criteria were used to evaluate the *BODR* options for structural integrity, seismic issues, navigation and life span. This information was used to make informed decisions on which bridge options will be evaluated in the *DEIS*, and is documented in this report, *TP 9*.

This step concluded with selection of Single Level Option 3 and Dual Level Option 5 for further evaluation in the *DEIS*. Remaining *BODR* Options 1, 2, 4 and 6 were eliminated from further consideration

Step 3 – *DEIS*

In Step 3, the two RTZB options selected in Step 2 (Options 3 and 5) will be evaluated as RTZB Alternatives in the *DEIS*. To support this process, the following technical papers will be developed:

- *TP 2 Foundations for the Feasible Alternatives for the RTZB*
- *TP 3 Risk Assessment of the Feasible Alternatives for the RTZB*
- *TP 5 Cost Estimate for the Feasible Alternatives of the RTZB*
- *TP 6/7 Construction of the Feasible Alternatives for the RTZB and Landings*
- *TP 8 Visualizations of the Feasible Alternatives for the RTZB*

These reports and the drawings that accompany them have provided a structured mechanism to explore the issues captured in their titles. As a result, the documents and the engineering issues they address have evolved as questions have been identified, issues have been considered, and designs modified.

Development of Evaluation Criteria

Based on the *R&R Report*, the study sponsors recommended that the TZB should be replaced. To undertake that alternatives analysis, criteria to evaluate the bridge options were established. These bridge evaluation criteria encompass aspects of engineering, transportation, environment and cost. These criteria were presented to the Bridge SAWG at a regular meeting in November 2007, and to the public at the Scoping Update meetings held during February 2008. The criteria were also included in the Scoping Update Packet transmitted to all participating and cooperating agencies as well as all other stakeholders. No objections to the proposed criteria were received.

Within the broad categories of engineering, transportation, environment and cost, specific topics such as structural integrity, emergency response, transit ridership, displacements and acquisitions, and capital cost were identified as areas to be investigated. Many of these topics have well established methods of analysis that enabled the project team to identify whether a particular design option meets minimum requirements and thus is feasible, is appropriate to its context and thus is suitable, can be simply constructed or otherwise provided and thus is practical and has impacts that are manageable and less than or greater than those of other options. As multiple options may satisfy these requirements, the criteria provide a means to differentiate between possible options. At this stage of the analysis, Operating and Maintenance Costs, and Life Cycle Costs were not employed.

The criteria used in the *R&R Report* have been enhanced to allow for the more detailed evaluation of the possible *DEIS* RTZB options. The RTZB options identified in the *BODR* (Step 1) have been evaluated using select engineering criteria along with acquisitions and displacements from the environmental criteria. The six RTZB options selected from the *BODR* have been evaluated, in their Initial Build and Final Build conditions, in *TP 9* (Step 2). The bridge evaluation criteria employed in Step 2 are listed in Table 1.1.

Engineering	Transportation	Environmental		Cost
		Construction	Operation	
Structural Integrity	Roadway Congestion	Displacement Acquisitions	Land Use	Capital Cost (cable stayed bridge)
Operations and Risk	Alternative Modes	Historic Resources	Displacement Acquisitions	Operating and Maintenance Cost
Seismic	Mode Split	Archeological Resources	Historic Resources	Life Cycle Costs
Redundancy	Transit Ridership	Parkland 4(f)	Archeological Resources	
Emergency Response	Non-Vehicular Travel	River Ecology	Parkland 4(f)	
Navigation	Reserve Capacity	Community Noise	River Ecology	
Life Span	Transportation System Integration		Avifauna *TP 8*	
Construction			Visual	

Table 1.1 - Bridge Evaluation Criteria (shaded criteria were not utilized)

1.3 Community Involvement

Over the course of developing the optional TZB bridge configurations, a number of outreach meetings were held with project stakeholders and members of the general public. Bridge SAWG meetings were held approximately every month. Meetings were also held with cooperating agencies, federal partners, elected officials from the landing communities (August 2009), Environmental, Transportation and Bike Pedestrian SAWGs, community stakeholders from the corridor (November 2009) and through a series of open houses with the general public (November/December 2009). All comments received were considered in the development and evaluation of all configurations.

1.4 Purpose of this Report

This report takes the six optional RTZB cross-sectional configurations identified in the *BODR* and evaluates them on the basis of an expanded set of project engineering, transportation, environmental and cost criteria to select single-level and dual-level RTZB options for further development and evaluation in the *DEIS*.

After reviewing the programmatic and physical requirements for the crossing, then the options proposed, this report examines each of the criteria topics and evaluates the bridge options against these criteria, concluding with a recommendation of options to be considered further in the *DEIS*.

This report examines the function of the RTZB and the elements it must contain in order to satisfactorily provide for the highway, bus, rail, pedestrian and cyclist users of the RTZB. These include direct needs, such as roadways, paths and railroad infrastructure, as well as ancillary needs: shoulders, barriers, maintenance, emergency operations, redundancy, seismic resiliency, etc.

The report also examines the fit of the RTZB, both into its physical environment, as well as options for its construction. This includes examining the CRT and BRT connections on and off the bridge, the physical terrain both in the river and on the landings, and the limited space available within which to construct the RTZB.

This report builds upon the BODR by expanding upon the assessment of operations and risks, identifying transportation aspects of the options, identifying both operating and construction environmental impacts and assessing capital, operations and maintenance and life cycle costs.

This report first describes the single-level RTZB options, including characteristics of the replacement bridge, the Rockland and Westchester landings, the sequence of construction and any non-standard features. The report then evaluates the three single-level options against the full set of bridge evaluation criteria. The report concludes that **Option 3, Single Level CRT Center Two-Structures**, be recommended for further consideration in the *DEIS* and that Options 1 and 2 be eliminated from further consideration.

The process is repeated to describe, evaluate and recommend a dual-level RTZB option from the three dual-level options carried forward from the BODR. The report concludes that **Option 5, Dual Level CRT North** be recommended for further consideration in the *DEIS* and that Options 4 and 6 be eliminated from further consideration.

The single-level and dual-level options resulting from this report will serve as a common element among the project's four build alternatives (B - E) for evaluation in the *DEIS*.

1.5 Bridge Options

As described above, the *Scoping Summary Report* identified that all project alternatives include a replacement Tappan Zee Bridge which would include:

- 8 general purpose highway lanes (4 in each direction) with shoulders
- 2 BRT lanes (1 in each direction)
- 2 CRT tracks
- Shared Use Path

As described in section 1.2 under Step 2 of the RTZB Selection Methodology, the *Bridge Options Development Report* (*BODR)* documented the identification and selection of six RTZB configuration options for further evaluation and possible association with the project's four build alternatives to be progressed into the *DEIS*.

Subsequent to its selection in the BODR, Option 3 was modified to enable a phased implementation of CRT. In its original configuration (

Figure **1.3**), the superstructure consisted of two decks, each carrying one CRT track, one BRT lane and four Highway lanes, plus shoulders. To provide similar sized decks, the north structure carried the SUP, while the south structure carried the CRT maintenance way.

In the revised configuration (Figure 1.4), the CRT was given its own deck, similar to Option 1. However, instead of being supported by a column (as in Option 1), it was supported by a crosshead beam tied into the two columns that characterized the original Option 3. The revisions to Option 3 were reviewed extensively with the members of the Bridge SAWG beginning in April 2010.

With the revisions made to Option 3, the configurations screened from the *BODR* and selected for consideration in *TP 9* are the following six options (Figure 1.5).

Figure 1.3- Option 3 (*BODR* Version)

Figure 1.4 - Option 3 (*TP 9* Version)

Option 1 - Single Level CRT Center Three-Structures Two single-level Highway BRT (HOV/HOT or Busway) structures with a third CRT structure in the center

Option 2 - Single Level CRT South Three-Structures Two single-level Highway BRT (HOV/HOT or Busway) structures with a third CRT structure to the south

Option 3 - Single Level CRT Center Two-Structures Two single-level Highway BRT (HOV/HOT or Busway) structures with a CRT deck located in between supported by a crosshead beam

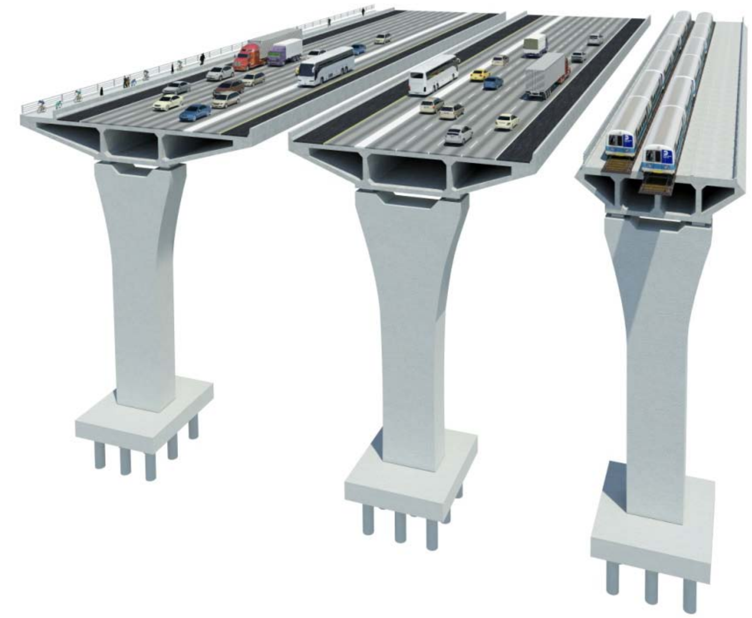
Option 4 - Dual Level Stacked A hybrid stacked single structure with two Highway BRT (HOV/HOT or Busway) decks above a centrally located CRT deck supported by a crosshead beam

Option 5 - Dual Level CRT North Two dual-level Highway BRT (HOV/HOT or Busway) structures with CRT in the north bay

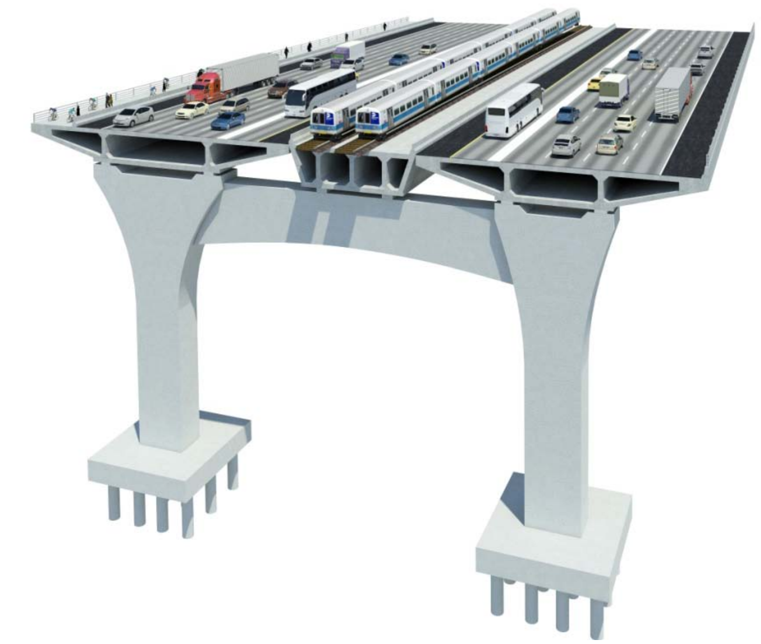
Option 6 - Dual Level Transit Below Two dual-level structures with only Highway above and CRT in the north bay and BRT (Busway) in the south bay

These options are listed to the right and the cross sectional arrangements of their approach spans are depicted in Figure 1.5.

Option 1 – Single Level CRT Center Three Structures
Two highway/BRT (HOV/HOT or Busway) structures with a central CRT structure



Option 2 – Single Level CRT Center Three Structures
Two highway/BRT (HOV/HOT or Busway) structures with a CRT structure to the south



Option 3 – Single Level CRT Center Two Structures
Two highway/BRT (HOV/HOT or Busway) structures with a central CRT on added supporting crossbeam

Option 4 – Dual-Level CRT Center Stacked Option One Structure
Two highway/BRT (HOV/HOT or Busway) decks above a central CRT deck on a composite single structure

Option 5 – Dual- Level CRT North Two Structures
Two Dual-level structures with highway/BRT (HOV/HOT or Busway) decks above an CRT below on the North

Option 6 – Dual-Level Transit Below Two Structures
Two Dual-level structures with highway above and CRT below on the North and BRT Busway below on the South

Figure 1.5- Replacement Tappan Zee Bridge Options

2 Requirements for the Replacement Tappan Zee Bridge

This chapter lays out the various design criteria the crossing should meet. In some cases, exceptions to the design criteria are necessary and non-standard features are identified. This chapter also outlines the assumptions involved in developing the possible RTZB options and defines the study area encompassed by this study.

2.1 Design Criteria

Specific design criteria established for the RTZB enable the transportation modal requirements to be sized and establish additional physical requirements that impact the overall width of the bridge components. These are included in the *SSR* and are reproduced below in Table 2.1 for Highway and Table 2.2 for rail elements. Following these are requirements for the Mainline Concurrent BRT (HOV/HOT) Lane (Table 2.3) and Busway BRT Geometric Standards (Table 2.4)

	Critical Design Element	Standard Criteria	Source
1	Design Speed (mph)	70	HDM §2.7.1.1A; NYSTA
2	Minimum Lane Width (feet)	12	HDM §2.7.1.1B
3	Minimum Shoulder Width (feet) Left Right	4, 12 Desirable 10, 12 Desirable	HDM §2.7.1.1C, Exhibit 2-2; NYSTA
4	Min. Bridge Roadway Width (feet)	Match approach highway	BM §2.3.1, Table 2-1
5	Maximum Grade	3%	NYSTA
6	Horizontal Curvature, Minimum Radius @e=6% (feet)	2040	HDM §2.7.1.1F, Exhibit 2-2;
7	Maximum Super-elevation Rate	6%	HDM §2.7.1.1G
8	Min. Stopping Sight Distance (feet)	730	HDM §2.7.1.1H, Exhibit 2-2
9	Minimum Horizontal Clearance (feet) Without Barrier/Rail With Barrier/Rail	15 Shoulder width (not less than 4)	HDM §2.7.1.1I
10	Minimum Vertical Clearance (feet) Vehicular Bridges Pedestrian Bridges OH Sign Structures and Signs	14^, 16.5 Desirable^ 17, 17.5 Desirable^^ 17, 17.5 Desirable^^	HDM §2.7.1.1J BM §2.4.1, Table 2-2;
11	Pavement Cross Slope	1.5% min 2% max	HDM §2.7.1.1K
12	Maximum Rollover Between Lanes At edge of Traveled Way	4% 8%	HDM §2.7.1.1L
13	Structural Capacity	HL-93, NYSDOT Design Permit Vehicle, additional long-span criteria based on bridge type	AASHTO LRFD §1.1, §3.6 HDM §2.7.1.1M BM §2.6
14	Minimum Level of Service	C, D with supporting documentation	HDM §2.6.14, §2.7.1.1N, Heavily Dev Urban Area
15	Control of Access	Full	HDM §2.7.1O
16	Pedestrian Accommodation	Prohibited, under legal review	21 NYCRR, Chapter 3A, §102.1; NYS Highway Law, Article 1, §3.2
17	Minimum Median Width	10	HDM §2.7.1.1P
Additional River Criteria			
18	Minimum Clearance Over Shipping Channel (feet)	139 at Existing Piers, 155 Desirable	U. S. Coast Guard Provisional Requirement
19	Minimum Navigation Channel Width (feet)	600	U. S. Coast Guard Provisional Requirement

^ Allow 6" additional for future resurfacing. 16.5' Desirable per TSDM §1.8.1.
^^ The 17.5' desirable vertical clearance for Pedestrian Bridges and OH Structures & Signs is based on TSDM Sec 1.8.2
Note: The Tappan Zee Bridge is part of a Qualifying Highway.

Table 2.1 - Tappan Zee Bridge - Highway Geometric Design Criteria

	Element	Standard Criteria	Source
1	Design Speed (mph)	90	MNR MW4 57.1(C) i
2	Gage (inches)	56.5	AREMA 2.1.1.4a; MNR MW4 53.0(C)
3	Maximum Grade Compensated Gradient Adjustment	1.5%, 2% for short distances 0.04% per Degree of Curve	MNR MW4 62.0(C); AREMA 5.3.7.1
4	Maximum Superelevation (inches)	5	MNR MW4 57.0(C)
5	Maximum Superelevation Unbalance (inches)	3	MNR MW4 57.0(C)
6	Minimum Horizontal Curvature	1°30'	AREMA 5.3.3.1g Table 5.3.2
7	Length of Spiral (feet)	As determined by using the greatest length obtained from the formulas in subsection (j)	MNR MW4 57.4(C)
8	Minimum Vertical Curve Length (feet)	L = (D x V² x 2.15)/0.6 [D= % grade change, V=speed (mph)]	AREMA 5.3.6, Passenger Lines; MNR MW4 62.4(C)
9	Minimum Horizontal Clearance (feet)	9 from track center, AREMA 8.5 from track center, NYS Law 25 without crash wall	AREMA figure 28.1.1 NYS Railroad Law §51-a.2; BM 2.5.3, Figure 2.6
10	Minimum Vertical Clearance (feet) (see diagram below)	23 above rail, AREMA 22 above rail, NYS Law	AREMA Figure 28.1.1; NYS Railroad Law §51-a.1; BM 2.5.3, Figure 2.5
11	Minimum Track Centers Separation (feet)	14, tangent 13.5 NYS Law	MNR MW4 62.1(C); NYS Railroad Law §51-a.4
12	Structure Live Load Freight Commuter Rail Only	Cooper E80^ 286,000 lbs GRL Historic 315,000 lbs GRL Proposed 80,000 lbs Maximum Axle Load Not set	AREMA 8.2.2.3c, 15.1.3.3a
13	Electrification (See Diagram Below)	Bottom Contact 3rd Rail 700 volts DC power	MNR drawing SP-101
14	Safety Walkways (inches) 1. Walking Surface 2. 56" Above Walking Surface 3. 80"Above Walking Surface (Headroom)	24 30 24	NFPA130, 6.2.1.11 Egress for Passengers NFPA130, 6.3 Construction Material
15	Minimum Clearance Over Shipping Channel (feet)	139 at Existing Piers, 155 Desirable	U. S. Coast Guard Provisional Requirement
16	Minimum Navigation Channel Width (feet)	600	U. S. Coast Guard Provisional Requirement

^ For the purposes of this report, a Maintenance Train Loading (Cooper E50, 50,000 lbs Maximum Axle Load) has been assumed.

Table 2.2 - Tappan Zee Bridge - Key Railroad Geometric Requirements

	Element	Standard Criteria^	Source
1	Design Speed (mph)	70	HDM §24.2.3.2
2	Minimum Lane Width (feet)	12, 11 With documentation	HDM §24.2.3.4A, §24.2.7.2; AASHTO HOV Facilities Guide
3	Minimum Left Shoulder Width (feet) BRT HOV Lanes Dedicated Enforcement Area (Left)	 10 2 14	HDM §24.2.3.4B, C, §24.2.7.2; AASHTO HOV Facilities Guide; FHWA HOT Lane Guide
	Right Buffer Area Width (feet) Minimum Maximum	1, 4 Desirable^^ 14, 10 Allowable^^	
4	Minimum Bridge Roadway Width (feet)	Match approach highway	BM §2.3.1, Table 2-1
5	Maximum Grade [Rolling]	3%	NYSTA
6	Horizontal Curvature, Min. Radius (feet) @e=8% @e=6%	 1810 2040	HDM §2.7.1.1F, Exhibit 2-2
7	Maximum Superelevation Rate	8%, 6% may be used in urban and suburban areas	HDM §2.7.1.1G
8	Minimum Stopping Sight Distance (feet)	730	HDM §2.7.1.1H, Exhibit 2-2
9	Minimum Horizontal Clearance (feet)	Shoulder width (not less than 4)	HDM §2.7.1.1I; AASHTO HOV Facilities Guide
10	Min. Vertical Clearance (feet) Vehicular Bridges Rehabilitation* Replacement** Pedestrian Bridges OH Sign Structures and Signs	 14, 14.5 Desirable 14¤, 16.5 Desirable¤ 15, 17.5 Desirable¤¤ 15, 17.5 Desirable¤¤	HDM §2.7.1.1J; BM §2.4.1, Table 2-2
11	Pavement Cross Slope	1.5% min; 2% max	HDM §2.7.1.1K
12	Maximum Rollover Between Lanes At edge of Traveled Way	 4% 8%	HDM §2.7.1.1L
13	Structural Capacity Rehabilitation* Replacement**	 HS20, H25 Desirable HL-93, NYSDOT Design Permit Vehicle	HDM §2.7.1.1M; BM §2.6; TSDM §2.1
14	Minimum Level of Service	Higher than General-Use Lanes, not less than C	HDM §24.2.3.3
15	Control of Access	Designated Ingress/Egress Locations	HDM §24.2.7.3
16	Pedestrian Accommodation	Prohibited	NYS Highway Law, Article 1, §3.2
17	Minimum Median Width (feet)	22	HDM §24.2.7.2, Figure 24-13b

^ Concurrent BRT lane standards are governed by those of the adjoining Thruway mainline. See Table D-12.
^^ Buffer widths between 4 feet and 10 feet are not deemed appropriate.
* Structure Rehabilitation excludes deck replacement.
** Structure Replacement includes new, reconstruction, and superstructure replacement.
¤ Allow 6" additional for future resurfacing. 16.5' Desirable per TSDM §1.8.1.
¤¤ The 17.5' desirable vertical clearance for Pedestrian Bridges and OH Structures and Signs is based on TSDM Sec 1.8.2

Table 2.3 - Concurrent Mainline BRT (HOV/HOT) Lane Geometric Standards

	Element	Standard Criteria			Source
		Single Lane One-Way	Barrier Separated Two-Way	Undivided Two-Way	
1	Design Speed (mph)	70	70	45	HDM §24.2.3.2, §24.2.6
2	Minimum Lane Width (feet)	12 , 11 with documentation	12 , 11 with documentation	12 , 11 with documentation	HDM §24.2.6.2 Figs. 24-11, a, b
3	Minimum Shoulder Width (feet) Left Right Enforcement Area	2, 4 Des. 8, 10 Des. 14	2, 4 Des. 8, 10 Des. 14	- 8, 10 Des. 14	HDM §24.2.6.2 Figs. 24-11, a, b
4	Minimum Bridge Roadway Width (feet)	Match Busway width	Match Busway width	Match Busway width	BM §2.3.1, Table 2-1 TSDM
5	Maximum Grade [Rolling]	4%	4%	7%	HDM §2.7.1.1E, Exhibit 2-2; HDM §2.7.2.2E, Exhibit 2-4
6	Horizontal Curvature, Min. Radius (feet) @e=8% @e=6% Undivided @e=4%	1810 2040	1810 2040	 711	HDM §2.7.1.1F, Exhibit 2-2; HDM §2.7.2.2F, Exhibit 2-4
7	Maximum Superelevation Rate	8%, 6% allowed in urban/suburb areas	8%, 6% allowed in urban/suburb areas	4%	HDM §2.7.1.1G, §2.7.2.2G
8	Minimum Stopping Sight Distance (feet)	730	730	360	HDM §2.7.1.1H, Exhibit 2-2; HDM §2.7.2.2H, Exhibit 2-4
9	Minimum Horizontal Clearance (feet) Without Barrier/Rail With Barrier/Rail	15 Shoulder width (not less than 4)	15 Shoulder width (not less than 4)	15 Shoulder width (not less than 4)	HDM §2.7.1.1I
10	Minimum Vertical Clearance (feet)	14, 14.5 Desirable	14, 14.5 Desirable	14, 14.5 Desirable	HDM §2.7.1.1J, §2.7.2.2J; BM §2.4.1, Table 2-2
11	Pavement Cross Slope	1.5% min; 2% max	1.5% min; 2% max	1.5% min; 2% max	HDM §2.7.1.1K, §2.7.2.2K
12	Maximum Rollover Between Lanes At edge of Traveled Way	 4% 8%	 4% 8%	 4% 8%	HDM §2.7.1.1L, §2.7.2.2L
13	Structural Capacity	HL-93, NYSDOT Design Permit Vehicle	HL-93, NYSDOT Design Permit Vehicle	HL-93, NYSDOT Design Permit Vehicle	HDM §2.7.1.1M, §2.7.2.2M; BM §2.6, TSDM §2.6.1, 2.6.2
14	Minimum Level of Service	Higher than General Use lanes, not less than C	Higher than General Use lanes, not less than C	Higher than General Use lanes, not less than C	HDM §24.2.3.3
15	Control of Access	Full	Full	Full	HDM §2.7.1.1O
16	Pedestrian Accommodation	At Stations	At Stations	At Stations	ADAAG
17	Minimum Median Width (feet)	NA	10	NA	HDM §24.2.6.2 Figure 24-11a, b

Prototypical Buses – Standard - 8.5 feet wide by 10 feet high by 30, 35, 40 feet long
Articulated - 60 feet long
Double articulated – 80 feet long

Table 2.4 - Busway Geometric Standards

2.2 Assumptions

In order to limit the scope of this study and evaluation of possible RTZB options for consideration in the *DEIS*, a number of assumptions are necessary regarding the physical extent of the study, the options possible in the physical form of the RTZB, and the possible methods and time periods of constructing the RTZB and its elements.

The following project elements are assumed for the purposes of this report:

- Study Area – From Interchange 10, South Nyack to Interchange 9, Tarrytown within existing right-of-way (ROW)
- Hudson Line Connector (HLC) Tunnel Option, both Short and Long depicted
- Shared Use Path (SUP) 16-foot width on north side
- Main Spans – Standard cable-stayed structure supported by pylon towers or arch structure
- Piles – Standard 4-foot diameter pipe pile assumed
- Toll Plaza – 3 Highway-speed E-ZPass lanes; 7 toll lanes

For costing and environmental assessment purposes, the cable-stayed structure supported by pylons has been assumed.

There are both busway and bus lane BRT alternatives. The busway by definition is comprised of two adjacent bus only lanes with shoulders outside. The bus lane alternative is defined as a BRT/HOV/HOT lane located adjacent to each of the leftmost high-speed highway lanes. This BRT/HOV/HOT lane is separated from the high speed highway lane by a buffer. On the RTZB, a project busway alternative can utilize a BRT/HOV/HOT lane configuration.

West of Interchange 10, the busway will be located along the south side of I-287. To transition from the busway into the center BRT/HOV/HOT lanes, a tunnel under-crossing beneath the eastbound lanes is anticipated. A flyover option is also possible. Both these options are just outside of the study area for this report and are not included in the analysis. For Option 6, the BRT buslane is below the highway deck. Like the other options, a tunnel transition from the busway is anticipated west of Interchange 10. For Option 6, the tunnel structure conveying the BRT buslane from the transition to the RTZB is included in the analysis.

The design criteria specify general purpose and busway lane widths of 12 feet and desirable vertical clearance of 16.5 feet over general purpose lanes and 14.5 feet over busway lanes. It identifies that minimum 4-foot left shoulders and preferably full 12-foot shoulders be provided outside the travel lanes and a 4-foot buffer between the highway lanes and the BRT/HOV/HOT lanes. A barrier width of 2 feet is assumed. For the SUP facility, a minimum lane width of 16 feet is specified.

The design criteria for the CRT components include a minimum horizontal clearance of 9 feet from track center, and a track centers separation of 14 feet. A minimum safety walkway width of 2.5 feet is specified at a minimum offset of 7.5 feet from track center. A Metro-North maintenance accessway of 12-foot width is provided at a 9-foot offset adjacent to the tracks. A vertical clearance over the rail of 23 feet is specified.

While the foregoing specify the width of the various modal components carried by the bridge, the bridge itself crosses a navigation channel, which has a minimum width of 600 feet. The project has identified a desirable minimum vertical clearance of 155 feet. With a tidal variation of +2.11 feet to Mean High High Water (Spring neap tide), the elevation of the RTZB is set at 157.11 feet at the edges of the 600-foot shipping channel. Because of the parabolic nature of the vertical profile of the bridge, the elevation at the center of the channel will be 158.0 feet.

The maximum grade of the CRT (maximum rise per distance traveled) is limited to 2 percent for short distances (approximately ½ mile), and 1.5% overall. These grades are further reduced to compensate for energy losses due to curvature. The CRT grades are generally 1.20% for the approach from Rockland, and 1.98% for the approach from Westchester.

Rail Loading

The *SSR* states "While freight is not a specific component of the project alternatives, the potential for freight will be considered in the bridge design so as not to preclude certain freight loadings." Further, the *SSR* states that, "Rail freight loading shall be based on Cooper E80 with 315,000 lbs GRL and 80,000 lbs maximum pending further assessment as part of the DEIS."

The *Freight White Paper* was prepared in August 2004 to determine if the development of a freight alternative is appropriate for inclusion in the Tappan Zee Bridge/I-187 Environmental Review. The paper explored the utility of freight operations on the RTZB in the context of regional freight needs, movements, facilities, and capacity of other means and methods of conveying freight across the Hudson River. The *Freight White Paper* concluded that ”there is no demonstrated market (existing or projected) for rail freight in the TZB/I-287 Environmental Review study corridor that would reasonably justify its inclusion for further study in the Draft Environmental Impact Study (DEIS).”

While it is recognized that the a full Cooper E80 freight loading will be considered in the RTZB designs progressed into the *DEIS*, for the purposes of this report, it is also recognized that a full freight loading will likely not be warranted, resulting in significant cost savings. A reduced loading is thus used in this report.

Four levels of rail-based loading are identified – two based on freight or maintenance requirements, and two based upon CRT requirements. The freight and maintenance loads are significantly greater than those required for CRT.

NYS law requires new rail structures provide capacity to carry a freight loading specified by the American Railway Engineering and Maintenance-of-Way Association (AREMA) and referred to as Cooper E80. This load arrangement comprises 2 locomotives and a trailing load of 8,000 lb per linear foot. For the purposes of designing the structures, this trailing load defines the overall structural requirements.

Because no freight alternative is being advanced, a reduced loading has been adopted as the basis for the RTZB designs progressed to date and described in this report. This reduced loading, referred to as a maintenance train loading (carrying ties or ballast), is similar to the Cooper E80 specification and comprises the same 2 locomotives; however, the trailing load is reduced to 5,000 lb per linear foot. As with the Cooper E80 specification, the trailing load defines the overall structural requirements. This report continues with the adoption of the maintenance train loading.

While all of the Options can be designed to accommodate the Cooper E80 freight loading, because the reduced maintenance train loading results in a lighter superstructure, there are cost reductions in both the superstructure and foundation elements. These cost reductions for the overall crossing are on the order of 10-15% for Options 1-4, but significantly less for dual-level truss Options 5 and 6.

To confirm for design purposes the maintenance train loading represents the greater load, CRT loadings were developed from MNR’s typical maximum length train configurations:

- 10 fully-occupied electromotive unit (EMU) cars (Bombardier M-7 equivalent)
- two locomotives (General Electric P32AC-DM equivalent) hauling 10 fully-occupied passenger coaches (Bombardier Shoreliner IV equivalent).

The fully occupied EMU M-7 train presents a load of 1,670 lb per linear foot. The locomotive drawn train has a load of 3,220 lb per linear foot through the locomotives and 1,460 lb per linear foot through the heaviest of the passenger cars. This report assumes the maintenance train reduced rail loading in its determination of structural requirements and consequent impacts and costs.

Initial Build Elements

Within the RTZB study area from Interchange 10 to Interchange 9, the elements listed in Table 2.5 are anticipated to be present in the Initial Build scenario. Specific elements that will not be constructed in the Initial Build scenario are listed in Table 2.6.

Highway	BRT	CRT	SUP
Reconstructed Interchange 10 with twin roundabouts and 4-ramp diamond	Center to south transverse tunnel – Rockland (Busway alternative only – closed until BRT is operational)	Short or Long Tunnel boxes under Toll Plaza, TBD	16-foot fenced walkway along north span
Reconstructed South Broadway Bridge (South Nyack)	Bridge Station Connector (maintenance vehicles only until BRT system is operational)	RTZB structural capacity for CRT (maintenance train)	Connections to South Broadway (South Nyack) and South Broadway (Tarrytown)
NY State Police facility at Interchange 10	Transverse Tunnel of Tarrytown Connector (maintenance vehicles only until BRT system is operational)		Connection to Esposito Trail (possible pedestrian bridge)
NYSTA Maintenance facility at Interchange 10	BRT tunnel under eastbound lanes and access transition – Rockland (Option 6 – maintenance vehicles only until BRT system is operational)		
Maintenance access road from Interchange 10 to Dockside			
4 12-foot lanes and 2 12-foot shoulders each direction			
central HOV/HOT lane each direction in Rockland (Buslane/HOV/HOT alternative only)			
central HOV/HOT lane each direction on RTZB			
Turnarounds			
Interchange 9 South Broadway eastbound on-ramp			
Highway speed E-ZPass lanes			
Reconstructed Toll Plaza with 7 toll lanes			

Table 2.5 - Elements constructed in the Initial Build scenario

Highway	BRT	CRT	SUP
Route 9/119 intersection	Busway south of I-287 in Rockland (Busway alternative)	Rockland tunnel	Connection to Riverwalk
	Broadway BRT Station	Rockland Portal and vent building	
	BRT Tarrytown Connector (TTC) ramp to Tarrytown rail station	CRT deck (and support system) across RTZB	
	BRT deck across RTZB (Option 6)	Short and Long Tunnel from Toll Plaza to Hudson Line	

Table 2.6- Elements not constructed in the Initial Build scenario

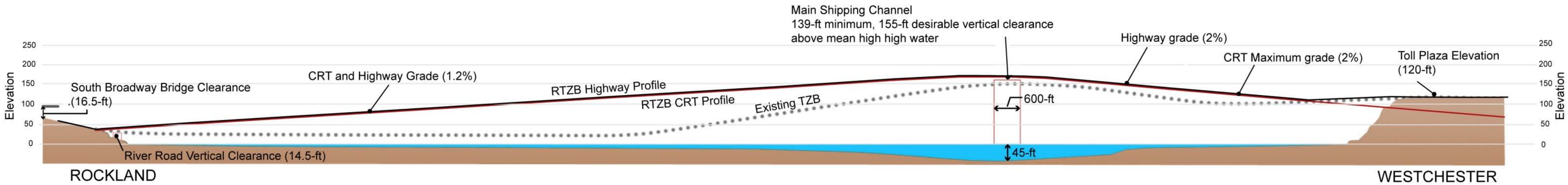


Figure 2.1- Proposed Highway and CRT Profile for a Single Level Replacement Tappan Zee Bridge

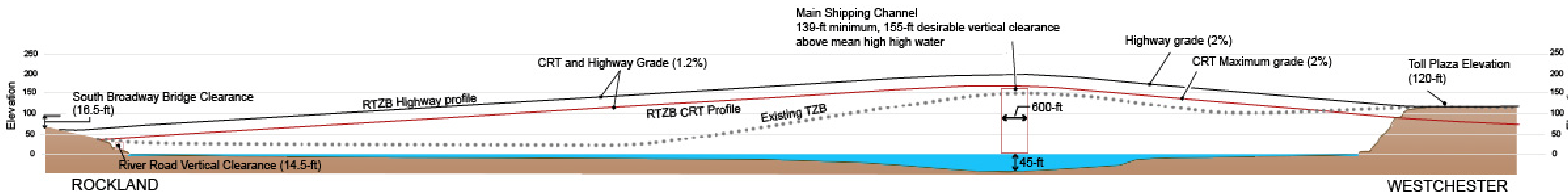


Figure 2.2- Proposed Highway and CRT Profile for a Dual-Level Replacement Tappan Zee Bridge

2.3 Hudson River

At the crossing, the Hudson River is actually at one of its widest locations, 2¾-miles from shore to shore. Because of the curvature involved in the Thruway approaches, the bridge itself is over 3-miles long. A profile of a single-level bridge alignment is provided in Figure 2.1, and that of a dual-level bridge in Figure 2.2.

The diversion of the Hudson River around Hook Mountain in Upper Nyack has created a 4000-foot wide 35-foot to 45-foot deep natural, channel on the eastern side of the Hudson. The center of the navigation channel is approximate ¾ of a mile from the Westchester shore. On each side of the river, the river bed drops off to 5-foot depth within approximately 1000 feet from shore. Beyond, the bottom is very flat. From the western side, the river bed descends gently down to a depth of 15 feet over a distance of 7500 feet. Upon reaching the edge of the main channel, the river bed drops off quickly to an ultimate depth of 35-45 feet. On the eastern side, the river bed is also rather flat and begins its drop off into the channel from a depth of 10 feet approximately 1500 feet from shore.

2.4 Bridge Alignment

The RTZB is a three dimensional object. To better understand the form of the bridge, one must look at the path the bridge takes - its alignment - from above in plan; and vertically from the side, in profile, along an important line such as the centerline. When looking down the length of the bridge along that centerline, one is considering its cross section.

North and south RTZB alignments, relative to the existing bridge, were identified, and considered within the *Alternatives Analysis Report*, dated January 2006. That report concluded that there is a preference for the north alignment based upon more space being available on the north side of the existing TZB at the Rockland landing, and a feasible though complicated construction staging at the Westchester landing. The south alignment would require a temporary trestle structure at the Rockland shore to reroute traffic and avoid significant property takings.

The question of a north or south alignment was taken up again in the *Alternatives Analysis for the Rehabilitation and Replacement of the Tappan Zee Bridge* report. Based upon the findings in this report, the project sponsors determined that the alignment of the RTZB should be to the north of the existing TZB for the following reasons:

1. There is available NYSTA ROW to the north of the existing TZB on both sides of the river that is sufficient to accommodate construction. Sufficient ROW is not available on the south side at the Rockland landing.
2. A north alignment allows for a straight approach to the Westchester Toll Plaza. A south alignment would result in conflict between the bridge horizontal curvature and the approach to the Toll Plaza.
3. The rail connection from the Hudson Line at the Westchester landing to the TZB aligns with the north side of the existing TZB.

4. Adequate space to accommodate the proposed Broadway BRT Station is located only on the north side of the existing TZB at the Westchester landing.
5. Storage and staging areas are available north of the existing bridge on both sides of the river.

2.4.1 Vertical Profile

The profile of the possible single-level structure is depicted in Figure 2.1 and a dual-level structure is depicted in Figure 2.2. A limited number of elements control the vertical profile of the RTZB. From west to east these include:

- South Broadway Bridge
- River Road
- Shipping Channel
- Hudson Line Connector
- Toll Plaza

The primary controlling feature is the clearance provided over the shipping channel. The existing TZB clearance is 139 feet at the Main Span towers abutting the shipping channel. The shipping channel is 600 feet wide. The tidal range of the Hudson at the TZB varies from Mean Low Low Water at elevation -2.08 feet below North American Vertical Datum of 1988 (NAVD88) zero datum, to Mean High High Water at elevation 2.11 feet.

Because bridges immediately north and south of the TZB provide vertical clearance of 155 feet or greater, a desirable clearance of 155 feet has been adopted as design criteria. Table 2.7 lists the bridges crossing the Hudson and their clearances from Troy-Rensselaer to the Atlantic. The Port of Albany is located just south of the Dunn Memorial Bridge.

Because the Main Span highway surface will likely be “arched” in the form of a parabola as it crosses the shipping channel, the center of the span will be higher than the two points where the span is over the edges of the shipping channel, which in turn will be higher than the height of the span at the location on the towers. It is anticipated that the underside elevation will be 157.11 feet at the west and east edges of the shipping channel, and lower at the towers and higher at mid-span.

On the Rockland side, two elements contribute to the profile west of the Main Span. The first is the underside of the highway and CRT structures must be above elevation 30 feet to provide adequate clearance above River Road. This applies to both dual and single-level structures. Thus, the clearance over River Road and the structural depth of the span determines the elevation of the deck at the abutment. Structural depths for single-level decks are on the order of 15 feet for the 230-foot spans considered. This would place the highway and CRT at elevation 45 feet as they reach the Rockland shore. For dual-level structures, the structural depth is 35 feet overall with 6 feet under top of rail for 430-foot spans. This would place the CRT at approximately elevation 36 feet with the highway at elevation 65 feet over River Road.

The other concern is that the roadway surface cannot be higher than elevation 60 feet at the South Broadway Bridge, located 1200 feet inland from River Road. Since the CRT can continue to descend as it enters the tunnel to cross under the Palisades, the dual-level highway above it can also descend. Adequate clearance under South Broadway Bridge can thus be maintained.

The navigational clearance (vertical and horizontal) and the structural depth of the CRT at the Main Span determine the elevation of the CRT at the east tower of the Main Span. To minimize the length of the tunnel required to reach the Hudson Line, the CRT then descends at the maximum permissible grade. This brings the CRT portion of the RTZB into the side of the Westchester escarpment. For simplicity of form in the bridge design, the highway structures are expected to proceed at the same grade as the CRT. For dual-level structures, the highway deck above follows the CRT. For both single-level and dual-level configurations, the highway decks must begin to curve upwards away from the CRT as they reach the shore in order to come out above the escarpment and into the Toll Plaza area.

Name	Route	Milepost	Clearance (ft)
Hoosick St	SR 7	132.9	60
Green Island	Federal St.	132.7	60
Congress Street	SR 2	132.2	55
Troy-Menands	SR 378	130.5	61
Patroon Island	I-90	127.8	60
Conrail	rail	127.2	swing
Dunn Memorial	US 9	126.4	60
Castleton-on-Hudson	I-90	117.9	135
Conrail	rail	117.8	139
Rip Van Winkle	SR 23	98.7	142
Kingston-Rhinecliff	SR 199	82.7	135
Poughkeepsie Railroad	peds	66.5	167
Mid-Hudson	US 44	66.0	134
Newburgh-Beacon	I-84	53.0	147
Bear Mountain	SR 6	40.6	155
Tappan Zee	I-87/I-287	23.5	139
George Washington	I-95	10.0	195
Verrazano Narrows	I-278		215

Table 2.7 - Hudson River Bridge Clearances

Rockland Approach - 1.2% grade versus 3% grade

In developing the Rockland Highway approach, two alternate vertical profiles are available for Options 1 and 2: adopt a version of the existing causeway approach, namely level then rapidly rising, or have the highway ascend parallel to and at the same grade as the CRT. This sub-chapter explores the issues (cost, safety, capacity, emergency response and aesthetics) presented by both vertical alignment options. It identifies a number of concerns with replicating the existing profile and recommends the highway decks follow the CRT instead.

From the Rockland landing to the Main Span, the existing TZB profile is level (0% grade), then rises at a 3% grade to the Main Span. This arrangement minimized the length of columns during the rise to the Main Span, and enabled use of shallow timber foundations through the level portion of the causeway.

The CRT cannot negotiate a 3% grade, thus an operationally efficient continuous grade of 1.2% from the crossing of River Road to the Main Span has been adopted for the Rockland CRT approach to the Main Span. By their configuration, the Highway/BRT decks of Options 3, 4, 5 and 6 must follow the profile of the CRT.

In selecting the appropriate profile for the Rockland Highway approach, a number of factors were considered. These are listed below and illustrated in the visualizations in Figure 2.3:

- Is the form of the existing causeway a feasible and prudent option for the Approach?
- Are there savings in foundation materials and costs?
- What effects does the steeper grade have on traffic, safety and capacity?
- How does the split grade affect emergency response to the CRT?
- How does the split grade affect the visual form of the RTZB?

Existing Causeway

The original TZB causeway was relatively economical, employing short spans, and thus many piers carrying modest loads that could be supported on the soft river bottom by thousands of wood piles. This lead to a substantial number of deck joints, which are difficult and costly to maintain, and which enable deicing salts and water to reach the underlying structural steel and concrete piers, leading to their accelerated corrosion and de-lamination. To avoid these costly and disruptive life-cycle maintenance issues, long-span decks of few joints, and piers with longer pipe-pile foundations were adopted for all options. Replacing the existing causeway with a similar structural form was feasible but not prudent.

Costs

To raise the Highway/BRT decks alongside the CRT requires gradually increasing column heights. If the Highway/BRT decks followed the existing profile of the TZB causeway, column heights would remain short then rise at 3% to the Main Span. This would reduce overall material quantities in the columns and the reduced weight would also reduce foundation requirements. For example at pier #27, which has the greatest height difference, there would be a 22% reduction in pile numbers and 44% reduction in pier quantities with consequent reduction in costs. However, these differences only account for the substructure components with no reduction in the quantities or cost for the superstructure above the piers, which accounts for more than 50% of the cost of the RTZB. Incorporating superstructure costs identified an overall cost reduction of approximately 5%.

The cost difference does not include the costs for the eastbound climbing lane that based upon the traffic effects, would be warranted for the 3% grade option. The addition of the cost for the climbing lane in advance of, through and beyond the 3% grade – a distance of approximately 5000 feet (which would require more robust columns and negate the savings in foundation costs) would further reduce the difference in cost between the options. As a result, the cost difference between the 1.2% and 3% profiles is considered trivial.

Traffic, Thruway Capacity and Accident Rates

The 3% grade will create gaps in traffic as some vehicles fail to maintain their speed as they start to climb. As vehicles slow relative to others, gaps are created ahead of them, while vehicles behind are progressively slowed, producing reactions that travel upstream in the traffic flow, and under heavy traffic conditions produce stop and go conditions. The slowing also induces drivers to make more passing moves, increasing turbulence and directly increasing the potential for accidents. The turbulence, like the gaps, further reduces capacity across the road section. Vehicles traveling at a constant speed along a lower grade, such as 1.2%, would not have occasion to suddenly slow or fail to keep up.

The loss of capacity can be significant, and for the eastbound Rockland approach could be on the order of 1000 vehicles per hour, approximately half the capacity of a lane, and warranting the addition of a 5th climbing lane. Under moderate to heavy traffic conditions, the grade would work in an automatic way, repeatedly slowing a segment of the driving population, particularly trucks, and buses, resulting in reduced speeds as well for the overall driving population. **The spot loss of capacity and throughput induced by the 3% grade would result in the reduction of the overall capacity of the bridge and the Thruway with permanent effects on the ability of the RTZB and the corridor to meet it objectives** to safely and efficiently provide for the mobility needs of the region, as well as permanently curtail the ability of the Thruway to convey the volumes that it requires for the solvency of the rest of the system.

Over the course of its intended 150-year design life, a 3% grade in the Rockland Approach will result in significantly higher accident rates. Accident rates for the Rockland approach to the main spans of the existing TZB are significantly above the statewide average and are directly related to the existing grades.

Emergency Response

Another major concern with the 3% grade is the vertical separation it creates between the highway and the CRT and the inability to provide assistance to the CRT in the event of a major train incident. The proposed CRT maintenance access road would be unsuitable to stage and mount a firefighting operation or to facilitate emergency response to injured persons, or evacuate passengers. Should a major train fire occur while the CRT was on the Rockland Approach, responding fire crews would find themselves frustrated in their attempts to reach the fire and fight it effectively. The best that could be hoped is that the streams of water from their hoses could reach across the gulf between the structures to beat down the flames, knowing full well that water is inappropriate to either electrical fires or burning diesel fuel. The means to provide expedient direct assistance to victims would be virtually nonexistent.

Visual Effect

Finally, the context for the Tappan Zee Bridge is an area with significant beauty with real attributes that include the low scale tree-filled communities along both the Palisades and Westchester escarpments, the expanse of the Hudson, the indomitable Hook Mountain to the north and a quality of light that has inspired painters, photographers and visitors for over four centuries.

The 1.2% grade results in a similar height and depth of the highway and CRT deck giving the impression of a single unified TZB form across the Hudson River. Though its detailed form is to be determined later in the environmental/design process, the coincident deck structure of the 1.2% grade provides a simple and harmonious relationship with the river.

The 3% grade structure results in different elevations for the highway and CRT deck structures with adjacent pier heights differing by up to 50 feet (Figure 2.3). This condition stretches for approximately 10,000 feet from the Rockland landing to the main spans, approximately 60% of the full crossing length and greatly affects the visual environment. The presence of two different deck structures provides a significant visual change and disruption to the communities of Nyack, South Nyack and Grand-View-On-Hudson and is considered unsightly compared to the single deck and unified bridge impression create when the CRT and highway decks are at the same elevation.

Summary

While the cost reduction of using the existing configuration provides for shorter columns, what is not addressed are the effects of the steeper grade upon traffic operations and roadway safety, the ability to provide timely and effective access to the CRT structure by emergency personnel, the need to provide a 5000-foot climbing lane to accommodate the large number of commercial trucks that would be slowed by the increased grade, and the visually jarring and significantly more massive presence of two different deck alignments within the Tappan Zee of the Hudson River.

Given that the 3% profile results in unnecessary capacity reductions, significantly higher accident rates, and severely reduced emergency response for CRT, the use of this profile instead of the continuous 1.2% profile is fatally flawed. The resulting poor aesthetics of a split profile crossing is likewise considered a fatal flaw. Considering that a climbing lane affecting both the Approach and the Main Span would be required to ameliorate the loss of capacity, the cost differential between the 1.2% profile and the 3% profile is considered negligible, if not in fact more expensive (due to costs incurred for the needed climbing lane) for the 3% profile. For these noteworthy reasons, a 3% profile similar to the existing TZB profile has been eliminated.

2.4.2 Horizontal Alignment

The typical corridor width of 250 feet extends through the landing areas. On the north side of the Thruway in Rockland, once past the property corner of the Bradford Mews Apartments, the available NYSTA ROW flares out to provide an area over 175 feet wide between the highway boundary at the shoreline and the existing edge of the TZB. On the Westchester side, the available area is limited along the north by the highway boundary which abuts "The Quay" condominiums and the 303 Broadway office building. This north area is only 87 feet from the property line to the north edge of TZB at the last of the major TZB piers.

As the northernmost structure of the RTZB approaches the Westchester landing, the easternmost of its full length major spans would rest upon a pier located inboard of the Hudson Line tracks and the proposed Tarrytown Connector (BRT). As stated above, the available ROW opposite this pier is approximately 87 feet. It is anticipated that while the balance of the spans of the northernmost structure of the RTZB can be constructed to their normal full width, this last span may have to be constructed in stages.

Figure 2.3 – Cross-Section and Visualizations of the Option 2 Rockland Approach with a 3.0% Highway grade and 1.2% CRT grade

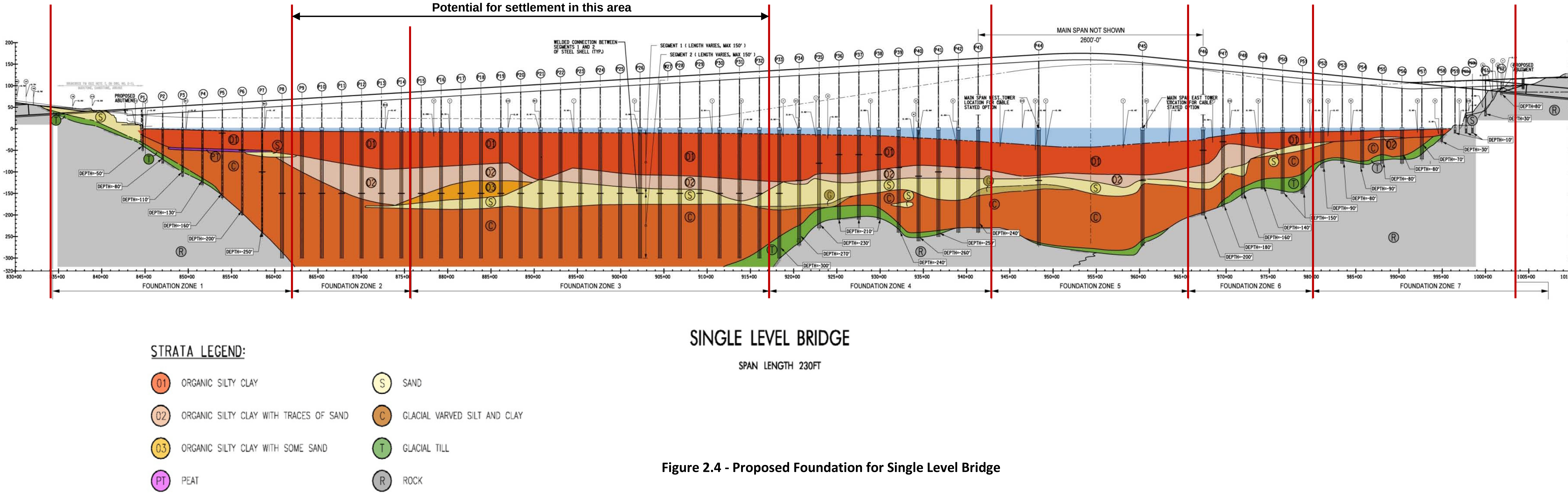


Figure 2.4 - Proposed Foundation for Single Level Bridge

2.5 Foundation Overview

The foundation types and installation methods depend on the type of soil profile under the Hudson River at the location of the RTZB. The Hudson River, between Dobbs Ferry and Stony Point, is tidal through the section making the environment more estuarine than fluvial. The geology in this area is very complex with deep profiles of soft organic clays overlying deposits of glacial sand and thick silts and clays. The rock is of varying type and quality with a highly irregular profile. In some areas within the river, the rock surface is practically unreachable, while on both shorelines, the rock is visible and near to the surface. In order to assess foundation alternatives, the crossing has been divided into five foundation zones. These zones represent areas of similar foundation types, capacities and performance characteristics.

In Zones 2 and 3, in the western half of the river, the potential for settlement of the approach structures is significant. Settlement of the substrate by up to 10 inches is expected over the life of the RTZB. Fifty percent of the total settlement is expected to occur in the first 10 years after construction and the remainder over the life of the bridge. Given the fluvial nature of the deposits, transverse differential settlement is expected to be minor. Longitudinal settlement, however, will introduce a sag in the profile through Zones 2 and 3 with the greatest longitudinal difference in settlement at the transitions between the columns founded in clay and those founded in the glacial till or rock.

Driven open end and closed end pipe piles ranging in diameter from 18 inches to 10 feet were considered for support of the RTZB. Other types of driven piles such as H-Piles were not considered as the circular cross section of the pipe pile is a more efficient means of resisting the lateral forces due to seismic loads. The static vertical geotechnical capacity of piles has been estimated based on the calculated end bearing capacity of the pile and the friction that develops along the pile's surface. Capacities in sands and clays are calculated in different ways due to the differences in soil behavior.

Advances in pile driving technology and equipment enable a large range in pile diameter, pile type and pile lengths to be considered for support of the bridge. Based on both the vertical and horizontal bridge loads and the soil conditions at the site, small diameter piles less than 36 inches are not practical. Using these small diameter piles would require a significant number of piles and large pile caps, which would increase schedule, costs and environmental impacts.

A study of large diameter piles such as 10-foot piles is also underway. These piles offer an advantage of achieving large vertical and horizontal capacities with relatively few piles. Using large diameter piles reduces the number of piles required, may reduce the size of the pile caps and thereby reduce overall cost. The larger diameter piles are only practical where the soil and underlying rock can support the high loads of the piles.

A 48-inch pile solution has been considered as a standard solution since the work can be done using ordinarily available equipment. This foundation type has been used in this assessment for cost estimation and schedule development.

2.6 Bridge Type Overview

The bridge type study documents the review of potential Approach and Main Span structural bridge type solutions. It identifies the configurations that are likely to prove workable based on engineering and operational requirements. These options were evaluated using design criteria particular to the modes, the bridge and the landings.

The *BODR* (with Option 3 modified as described above in Section 1.5) identified six bridge configurations with a range of geometric arrangements and loading requirements. For the purpose of discussing possible structural solutions appropriate for each of these configurations, the six configurations can be regarded as either a Single Level Option or a Dual Level Option. The bridge type study identifies a range of potential structural solutions for both the Single Level and Dual Level Approach structure, and recommends two structural solutions for the Main Span section, either of which is possible for each single and dual level option.

<table>
<tr><th></th><th></th><th></th><th>Approach Span</th><th>Main Span</th></tr>
<tr><td>1</td><td>CRT in center with three Approach Structures
Two highway/BRT (HOV/HOT or Busway) structures with a central CRT structure</td><td rowspan="3">Single Level Options</td><td rowspan="3">Steel Plate Girder
Steel Box Girder
Precast Concrete Box
Precast Concrete Beam</td><td rowspan="6">Cable-stay structure
Arch structure</td></tr>
<tr><td>2</td><td>CRT on south side with three Approach Structures
Two highway/BRT (HOV/HOT or Busway) structures with a CRT structure to the South</td></tr>
<tr><td>3</td><td>CRT in center with two Approach Structures
Two highway/BRT (HOV/HOT or Busway) CRT decks</td></tr>
<tr><td>4</td><td>Stacked
Two highway/BRT (HOV/HOT or Busway) decks above a central CRT deck on a composite single structure</td><td rowspan="3">Dual Level Options</td><td rowspan="3">Steel Truss</td></tr>
<tr><td>5</td><td>CRT below on north side
Two Dual-level structures with highway/BRT (HOV/HOT or Busway) decks above and CRT below on the North</td></tr>
<tr><td>6</td><td>All Transit below
Two Dual-level structures with highway above and CRT below on the North and BRT Busway below on the South</td></tr>
</table>

Table 2.8 - Summary of recommended approach and main span bridge type solutions

2.7 Construction Overview

The construction assumptions for all bridge options are as follows:

- The sequence of construction will be such that the north (westbound) highway structure would be completed first. This will enable all traffic from the existing bridge to be temporarily relocated to this structure until such time as a portion of the existing bridge is demolished and the remainder of the new bridge is constructed. The details of this sequence will be summarized in *TP 6/7 Construction of Feasible Alternatives for the RTZB and Landings*.
- Dredging will be required for all options in order to provide safe and workable access to the bridge site for the large number of vessels anticipated during the construction of the new bridge. These vessels would likely include the following:
  a. A variety of crane barges with the largest crane size not to exceed 500 tons.
  b. A range of delivery barges used for delivering large scale prefabricated bridge elements such as piles for all options, precast concrete segments for the superstructure of options 1 through 4 and steel trusses for the superstructure of options 5 and 6.
  c. Tug boats of various sizes for moving the vessels identified above. *TP 6/7* has identified that the capacity of the tug boats would range between 600 to 1800 horsepower.
  d. Dredges and scows used for the dredging operation itself.

The geometry of the dredged channel would be based on the operational requirements of the vessels identified above and explained in detail in *TP 6/7*.

- The bottom of the dredged channel would be armored with a 2-foot layer of sand and gravel. This feature is required to prevent propeller scour generated from tug boat operations.
- For all options, it is anticipated that dredging would be accomplished in three phases. Each phase would occur during a window within a calendar year. Pending final agreement, a dredging window not exceeding a total of three months has been assumed. The first dredging phase would occur at the very beginning of construction, the second phase would occur exactly a year from the first phase and the third and final phase would occur near the time of demolition of that portion of the existing bridge which overlaps with alignment of the new bridge.
- It is anticipated that about 80 % of the spoil from the dredging operation would meet the requirements to be disposed of at the Historic Areas Remediation Site (HARS) located in the Atlantic Ocean about 20 nautical miles south east of the tip of Manhattan. The remainder of the spoil, which may contain contaminants, would be disposed of at an upland site or sites after being treated at a transfer facility.
- Near each shore of the river, a temporary access platform will be constructed at a very early stage of construction. Comprised of a timber deck and steel piles, these platforms would provide access to construction equipment and material in a portion of the river where water depths are very shallow. The platforms will also serve as a docking facility for tug boats and crew boats and potentially serve as a “roll on-roll off” facility for construction equipment and material delivered by land. In particular, the platforms would facilitate concrete mixer trucks to board and de-board barges.
- Operations of the existing NYSTA Dockside maintenance facility at the Rockland landing will be maintained at all times during construction. During construction, a temporary docking facility would be provided at the temporary platform. After construction is complete, a portion of the Rockland platform would be converted to reestablish the existing NYSTA Dockside facility.
- For all options, staging areas will be required. The staging areas will consist of open spaces that would allow temporary storage for unassembled construction equipment and unassembled light duty bridge elements such as reinforcing bar cages and stay cables.

Staging areas will include a concrete batch plant for cast-in-place concrete bridge elements, temporary offices for engineering and administration staff and parking facilities for personnel involved in the construction of the bridge.

- Three types of foundation construction methods corresponding to three geographical zones of the bridge alignment will be employed for all bridge options as follows:

  Zone A: Foundations constructed from the temporary platform near the shores where water is very shallow - up to 7 feet deep.

  Zone B: Foundations constructed from floating barges where water depths are moderate – 7 feet to 18 feet deep. This comprises a majority of the bridge.

  Zone C: Foundations constructed from floating barges where water is deep –18 feet to 40+ feet. This condition occurs near the shipping channel and is applicable to the Main Span and some adjacent approach spans.

- All foundations will consist of driven piles. For the purpose of this report, it is assumed that Zone C foundations will be enhanced by means of rock sockets. All foundations will be constructed using cofferdams built from sheet piles. Cofferdams for Zones A and B will be conventional with sheet piles simply driven into the soil prior to driving the foundation piles. Cofferdams for Zone C foundations will be hanging cofferdams that will be assembled above the water level around the already driven piles, then lowered to the desired elevation.

  In all cases, the prime function of the cofferdams is to provide a “dry” condition in which the reinforced concrete footings can be built. To achieve this condition, the cofferdams will be dewatered after pile driving by means of sealing methods that may include a tremie concrete pour and a system of pumps.

  Cofferdams will also serve the additional functions of providing support for temporary templates that enable accurate positioning of the piles and for providing enclosures required to contain the air bubbles generated by any noise attenuating devices that might be used during pile driving.

- Piles will be driven using pile hammers in all options and in all zones. The numbers of piles in options 1 and 2 are significantly larger than the number of piles in all other options. This corresponds to a larger number of hammer operations as well for Options 1 and 2.

- Superstructure construction for Options 1, 2, 3 and 4 will entail precast segmental construction for which deliveries of concrete segments will be made on barges directly from a casting yard and erection will take place by means of over head launching gantries. The segments will be “clamped” together by means of post-tensioning and the top of the segments will serve as the deck for the roadway.

  Once the overhead gantry is installed and begins functioning, no barge mounted cranes will be necessary for this part of construction.

  For options 3 and 4 the CRT structure may be built using composite steel construction method.

- Superstructure construction for option 5 and 6 will entail delivery of large trusses on two barges connected end to end. This will be followed by a heavy lift of the truss onto the column top either by strand jacking or conventional winches. A lighter column unit will be erected prior to the erection of the truss by means of a barge mounted crane. Once the truss has been erected, precast concrete slabs will be lifted off of delivery barges and placed directly on the top chord of the trusses to serve as the roadway deck.

- Work on both Rockland and Westchester landings consists of new highway pavements and CRT tracks. It also consists of construction of new traffic circles, new overpasses, a Toll Plaza and some retaining walls. Construction of most of these items is unexceptional.

- A large effort during the construction of landings will be expended on traffic phasing so that traffic continues to flow uninterrupted on I 287 throughout the construction of the bridge. Among other operations this will entail construction of haul roads, installation and removal of temporary pavements, relocation of the Toll Plaza, installation and removal of temporary Bailey bridges, provisions for local staging areas and provisions of various traffic control devices such as lane striping, displacement of the temporary median and signage.

2.8 Bicycle/Pedestrian Path Overview

The project team is committed to accommodating pedestrian and bicyclists across the replacement TZB on a shared use path. The vision for the path is to provide a safe pedestrian and bicycle connection between Rockland and Westchester Counties and create an environment that provides a sense of place to experience the unique views.

As part of the process, a Bicycle/Pedestrian Advisory Panel (Panel) was formed and three meetings and an optional field trip were held. The Panel included representatives from adjacent communities at the landings and local bicycle/pedestrian advocates. To gather recommendations from the panel, the team reviewed connection options on each side of the Thruway and on both sides of the Hudson River. This included discussions about the connection options, elevations at the connections and key locations at the landings, ADA access, grades, and ROW impacts to adjacent properties. The Panel provided input as to which connections provided better connectivity to existing paths, viable grades for bicyclists, amenities on the bridge and at the connections, and overall concerns of community residents due to the potential influx of bicyclists.

A single wide path on the north side of the bridge was identified as providing the best connectivity to the bicycle/pedestrian facilities on the landings. It also was felt to have more unique views/vistas and reduced glare. On the Rockland landing, providing a connection to the Esposito Trail, near Interchange 10, would provide the best mobility for users. There was also interest in connecting to Cornelison and/or Smith Avenues to provide access to the local streets of Nyack. At the Westchester landing, the north side provided the best connection to the possible Broadway BRT station and to South Broadway and Route 119, which are both proposed to be signed shared roadways. While a 16-foot width has been assumed for planning purposes, the final width and design components will be formalized in detailed design. At that time, the following elements will be assessed as part of a world class facility:

- Width that allows for all users to travel in both directions and to pass one another safely
- Separation between high speed bicyclists and recreational users
- Universal design to accommodate all users
- Design the railing and other elements such that suicides are lessened
- Flexibility in design such that it is never completely closed for maintenance
- Good visibility, eyes on the path, and lighting to ensure safety and security
- Emergency response/maintenance vehicle access
- Maintain the lowest grade possible on the connecting paths to reduce effort for users
- Ensure sidewalks at the path connections
- Provide wayfinding and directional signage at decision points on the connecting paths

2.9 Common elements of the Landings

Through the landing areas, the RTZB transitions to the upland form. This section describes transition elements of the RTZB options that are common across these options.

2.9.1 Rockland Landing

The Rockland Landing contains a number of elements that are directly associated with the RTZB. Other elements represent a reconfiguration of existing facilities, while finally, several new elements not directly associated with the RTZB but directly affected by or instrumental to the construction of the RTZB will be introduced. The following listing identifies these Rockland elements:

New RTZB landing elements

- RTZB Abutment at River Road
- Approach highway transition (general purpose lanes and BRT (Busway/HOV/HOT) lanes)
- CRT portal
- CRT Vent building
- CRT Maintenance way transition
- BRT transition structure (for Busway options only)
- Shared Use Path transition
- Underground RTZB storm water treatment facility
- Highway patrol turn-around areas

Reconfigured landing elements

- Interchange 10
- Route 9W
- Removal of Franklin St. Bridge
- Reconfiguration of Route 9W, Highland Ave and Shadyside Ave connections
- South Broadway overbridge
- Esposito Trail
- Elizabeth Place Park
- Ferris Lane
- NYSTA Dockside facility
- Noise walls

New landing elements affected by the RTZB and its construction

- Relocation of the Westchester NYSTA facilities to Interchange 10
- Relocation of the Westchester NY State Police (NYSP) facilities to Interchange 10
- Direct maintenance access roadway between proposed NYSTA Interchange 10 facility and NYSTA Dockside facility
- Underground Rockland landing stormwater treatment facility
- Eastbound off-ramp to Interchange 10

Highway Transitions

On reaching the shore, the three decks pass over River Road providing 14.5 feet of clearance, then transition through their abutments. Each highway/BRT deck transitions directly to 4 highway lanes (with shoulders) and the buffer separated BRT/HOV/HOT lane.

The south edge of pavement would be in the vicinity of the middle of Ferris Lane and consequently would require a retaining wall along its southern extent. In order to provide access to the residences along Ferris Lane, it would be necessary to relocate Ferris Lane south, resulting in partial acquisitions from the adjoining properties.

The northernmost (westbound) highway deck is offset 71 feet south from the south property corner of the Bradford Mews apartment complex. This is to enable the inclusion of a maintenance access road between a proposed relocated NYSTA maintenance facility on the north side of Interchange 10, and the existing NYSTA Dockside facility on River Road. This maintenance access road would be in a cut and require sizable retaining walls.

Directly above this maintenance access road, the Shared Use Path (SUP) would continue from the north side of the RTZB to the east side of South Broadway and the north end of the bridge.

CRT Transition

Prior to reaching the shore, the CRT maintenance way separates from the CRT deck and descends to a secure staging area outboard of River Road. The two CRT tracks continue on a reduced width CRT deck. The CRT continues its descent (1.20% grade) into the Palisades, transitioning to a portal structure, whose sidewalls support the inside of the BRT/highway lanes.

Continuing west, the CRT portal transitions into a fully covered tunnel east of the South Broadway Bridge. This initial tunnel segment is referred to as the “start of tunnel” and is constructed using cut and cover methods because the overlying ground is too shallow to support construction either by mining or by the Tunnel Boring Machine (TBM) that will bore the balance of the tunnel. Where the start of tunnel is overlaid by highway, it will have to be pre-constructed at the time the highway is rebuilt. It is anticipated that a vent building for the tunnel will be required at a secure site in the vicinity of Interchange 10.

BRT Transition

In the BRT HOV/HOT alternatives, the two banks of eastbound and westbound BRT/Highway lanes converge together west of South Broadway. At this location, an emergency turnaround could be located. In the BRT Busway alternatives, the BRT busway lanes coming off the bridge would diverge from their adjoining highway lanes, and come together in the center to form a two-way Y-shaped ramp in between the highway lanes. This BRT only busway ramp would descend atop the roof of the CRT tunnel until sufficient clearance is obtained for the busway to pass under the eastbound lanes and emerge south of the Thruway. This transition would occur under Interchange 10, so that the busway could emerge south and west of the proposed eastbound off-ramp to Interchange 10.

South Broadway Bridge

The South Broadway Bridge would have to be fully reconstructed. In order to provide requisite clearance over the Thruway, a low span depth bridge deck is recommended. In order to also avoid issues of grade or the introduction of retaining walls in front of South Nyack Town Hall, it is recommended that South Broadway Bridge be reconstructed either in halves on its existing alignment or that it be offset by one half of the span width to the west. To facilitate this, it may be advisable to temporarily close South Broadway Bridge and develop a turn-around at the junction of South Broadway and Route 9W.

Interchange 10 Reconfiguration

To align the highway and Interchange 10 with the RTZB, this report anticipates the configuration of Interchange 10 will simplified to serve local traffic demands. A new crossing with roundabouts north and south of the Thruway would be introduced. The existing circular ramps would be removed and replaced with direct diamond ramps to and from the roundabouts. The South Franklin Street Bridge would be removed and the street rerouted into the north roundabout. The upper portion of Hillside Ave. (that continues from the existing interchange to S. Highland Ave.) would be tied into Shadyside Ave. The lower portion of Hillside Ave. (that continues from the existing interchange south) would be rerouted into the south roundabout. Continuation of Route 9W would be provided by introducing a northbound left turn bay in Hillside Ave. turning into a short dog-leg connection between Hillside and Shadyside avenues.

New and Reconfigured Facilities

The area north of the Thruway reclaimed from reconfigured Interchange 10 will become the site of the NYSTA maintenance facility relocated from Tarrytown. It will also house the NYSP Troop T Zone headquarters also relocated from Tarrytown.

2.9.2 Westchester Landing

The Westchester landing will also have to incorporate a number of elements. Several of these are directly associated with the RTZB. Others are existing landing elements that will be reconfigured. Finally, a number of new elements will be introduced that support future transit and other elements of the overall corridor improvement and are affected by or accommodated during the construction of the RTZB.

New RTZB landing elements

- RTZB abutments
- Transition highway trestle structure between crossing structure and abutments
- CRT portal
- CRT Hudson Line connector – box tunnel for Short or Long Tunnel alignment
- Possible CRT vent building
- CRT Maintenance way transition
- BRT Bridge Station connector to possible BRT station facility
- HOT/HOV lane continuation
- Shared Use Path transition
- Underground RTZB stormwater treatment facility
- Highway patrol turn-around areas

Reconfigured landing elements

- Interchange 9 ramps including South Broadway westbound on-ramp
- Route 9 overbridge
- Intersection of Route 9 and Route 119
- Relocation of existing NYSTA Bridge maintenance facility to Interchange 10 area
- Relocation of existing NYSP facility to Interchange 10 area
- Relocation of existing NYSTA East of Hudson maintenance facility
- Highway speed E-ZPass lanes
- Toll Plaza
- Toll Administration facility
-
- Highway patrol turn-around areas

New landing elements affected by the RTZB and its construction

- Proposed BRT Station north of I-287
- HOV ramps to Interchange 9
- North-south Maintenance and BRT tunnel under westbound lanes and Toll Plaza
- Underground Toll Plaza and upland approach stormwater treatment facility
- BRT Tarrytown Connector
- Cross County BRT roadway elements

Highway Transition

The highway lanes, while initially descending with the CRT, begin to curve upwards as they approach the Westchester shore, transitioning through a large fan-shaped structure that provides connection through the abutments to the westbound lanes and to the widened expanse of the eastbound Toll Plaza. At its abutments, the highway lanes are at approximately elevation 120 feet.

CRT Transition

The CRT needs to connect to the Hudson Line. Either the Short or Long Tunnel Option (described in Technical Paper 10, *Tunnel and Trestle Report*) provide the CRT Hudson Line Connector (HLC). Once past the Main Span, the CRT begins descending at its maximum grade (2%). Once past the East Main Back Span, the alignment curves to the southwest and the descending grade is compensated slightly to account for the curvature. Through the Main Span, Back Span and subsequent curve, the adjacent highway decks follow the same profile as the CRT. At approximately elevation 86 feet, the CRT proceeds directly into a tunnel within the hillside.

BRT Transition

In the eastbound direction, the BRT busway/HOV/HOT lane diverges to the center to create the eastbound leg of the Bridge Station Connector. In the BRT busway alternative, the lane continues briefly then merges into the leftmost high speed lane. In the BRT HOV/HOT alternative, the lane continues into the Toll Plaza losing its HOV/HOT status and becoming one of the high-speed E-ZPass lanes.

As the BRT system is programmed to serve the Tarrytown Metro-North railroad station, a connecting two-way BRT-only roadway between the proposed Broadway BRT Station and Tarrytown RR Station is expected. Due to the elevation change, it is proposed that this Tarrytown Connector (TTC) first pass south under the westbound lanes and the Toll Plaza, then curve west then north under the RTZB while descending to run alongside and inboard of the existing Hudson Line tracks.

Toll Plaza, Interchange 9 and the Shared Use Path

The Toll Plaza will consist of three high-speed E-ZPass lanes (with shoulders) on the left and 7 toll booths on the right, separated from the high-speed lanes by a barrier. To transition from the bridge to the Toll Plaza, the eastbound structure would be widened

Once past the Toll Plaza, the high-speed E-ZPass lanes continue to be segregated from the toll booth lanes to prevent dangerous weaving to the outside Interchange 9 exit.

In the westbound direction, the existing South Broadway on-ramp will be relocated to the northern edge of the NYSTA site. This ramp will merge with the 4 general purpose lanes at approximately the location of the abutment. An acceleration lane and merge taper will briefly result in a 5-lane cross section as the northern span proceeds from the shore.

North of this on-ramp, a connection to the shared use path (SUP) is provided from South Broadway to the SUP located along the north edge of the northern span. A connection is also proposed from the SUP to the walkways surrounding the proposed BRT station and parking facility.

2.9.3 Construction Sequence for the RTZB

While most of the RTZB will be constructed north of the existing TZB, portions of the new bridge will have to overlap the existing bridge at the landings due to space limitations. It is expected that the northernmost span can be almost fully constructed while the existing TZB continues to carry traffic. Because the center and south structures overlap the TZB at the landings, the ends of these structures cannot be completed concurrently with the north structure.

Once the north span is constructed, traffic would be shifted from the TZB to the north span. The TZB would be decommissioned and removal of the overlapping areas would commence. Any outstanding work on the north span would be completed to bring it up to full capacity of four 12-foot lanes in each direction. Remaining overlap areas of the TZB would be removed and the remainder of the center and south spans would be completed. With the south span fully constructed, eastbound traffic would be relocated thereupon. To accomplish this sequencing of traffic while providing access to construct the remainder of the RTZB and the upland areas (including the Toll Plaza), it is anticipated that traffic will have to be relocated in the landing areas.

On the Rockland side, in order to provide space for construction of the connection to the north structure, it is anticipated that widening of the eastbound approach will occur first (south of the existing lanes), then both eastbound and westbound traffic transferred thereupon while still feeding into the existing TZB. The north connection would then be completed.

A similar process would occur on the Westchester landing. At that location, a new set of westbound lanes would be constructed north of the existing, tying into the completed north span. Once completed, westbound traffic would be shifted to the north span, while eastbound traffic would continue to use the TZB and current Toll Plaza. Westbound portions of the TZB that are in the way of completing the north RTZB span would be removed and the north span completed. In the next stage, this central area between the relocated westbound lanes and the Toll Plaza would be modified to provide an eastbound transition from the north structure into the Toll Plaza along with additional toll booths added on the north. In this area, portions of the tunnel box for the HLC would be constructed and above this, the underground structures for the BSC and the TTC.

Once completed, eastbound traffic would also be shifted to the north span. The southern portion of the Toll Plaza, eastbound lanes and portions of the southern half of Interchange 9 would be closed off and rebuilt as necessary. The remainder of the HLC tunnel box and the south third of the TTC would be constructed. The ends of the TZB that interfere with construction of the remaining center and south spans of the RTZB would be removed and these spans completed into the landings. Eastbound traffic would then be shifted onto the south structure, making use of the reconstructed southern portion of the Toll Plaza, lanes and off-ramps. The center area that previously carried the eastbound lanes would then be reconstructed to complete the TTC tunnel box and to provide for the high-speed E-ZPass lanes, and relocation of the westbound lanes.

3 Single Level Options

3.1 Introduction

This chapter begins with a description how the single-level options place unique requirements on the configuration of the common elements of the Rockland and Westchester landings. It then describes the three options identified in the BODR to replace the TZB with a Single Level structure.

See Appendix A for detailed drawings of the three Single Level Options. Additionally, visualizations were created of the single-level options from a variety of locations on both sides of the Hudson River. The visualizations were created to allow the comparison of the configurations with regards to the number of piers and the bridge height and width and therefore, Options 1 and 2 are represented in the visualizations of Option 1. Visualizations can be found in Appendix B.

3.2 Single Level Landing Considerations

Rockland Landing

The controlling elevation of the RTZB at its abutment in Rockland is the elevation of River Road, the requisite clearance there at, and the structural depth of the RTZB decks. These three factors place the roadway and CRT decks at approximately elevation 45 feet at the abutment and enable the descending upland highway lanes (-2.56% grade) to transition to the ascending slope (1.2% grade) of the RTZB approximately 500 feet west of River Road.

With CRT and both Highway/BRT (HOV/HOT) decks on the same level, maximum use of available ROW is made, and in fact exceeded along the southern boundary for all single-level options, though to varying degrees resulting in various levels of acquisitions and displacements. Along the northern boundary, provision for the maintenance accessway to Dockside and SUP located above requires the acquisition and displacement of one property on the south side of Smith Ave.

With CRT located in either the center or the south position, the constrained available footprint requires that construction of the CRT be coordinated with that of the highway. If construction of the CRT elements is phased, access to the center or south CRT alignment will be limited and needs to be accommodated for during initial construction. For Options 1 and 3, future access to construct the CRT portal and start of tunnel portion could be made by temporary use of transverse ventilation shafts pre-constructed under the westbound highway lanes to a vent building located north of Interchange 10. For Option 2, future access to construct the CRT would be within a narrow area underlying Ferris Lane and outside of the reconstructed eastbound ramps of Interchange 10 requiring substantial additional land acquisitions and displacements.

Westchester Landing

Figures 3.1, 3.2 and 3.3 provide a plan, profile and cross section of the Westchester landing with the BRT, HOV/HOT and CRT alignments respectively depicted in green, blue and red. Like the Rockland landing, the single-level highway/BRT (HOV/HOT) lanes and CRT descend from the Main Span at a common grade and on one level. Unlike the Rockland landing, however, the CRT continues descending while the highway/BRT (HOV/HOT) lanes curve upwards and begin ascending approximately 2000 feet from the Westchester abutment. As the ascending highway/BRT (HOV/HOT) lanes approach the shore, the BRT(HOV/HOT) lanes split into two lanes (Point A on figures). The HOV/HOT lanes continue adjacent to the highway and the diverging BRT lanes from the south and north structures converge in the middle to form a Y-shaped two-way BRT ramp in between the highway/HOV/HOT lanes and above the descending CRT. This ramp, called the BRT Bridge Station Connector (BSC), continues to descend atop the CRT alignment while the highway and HOV/HOT lanes continue to ascend into the Toll Plaza. When adequate clearance is obtained over the BRT lanes, the BSC curves north under the westbound lanes to feed into the proposed BRT station.

In Options 1 and 3, the vertical profile of the BSC and consequently the vertical profile of the highway lanes are constrained by the central location of the CRT. Option 2, with CRT on the south would enable the highway lanes and BSC below to assume a lower profile on their approach to the Toll Plaza.

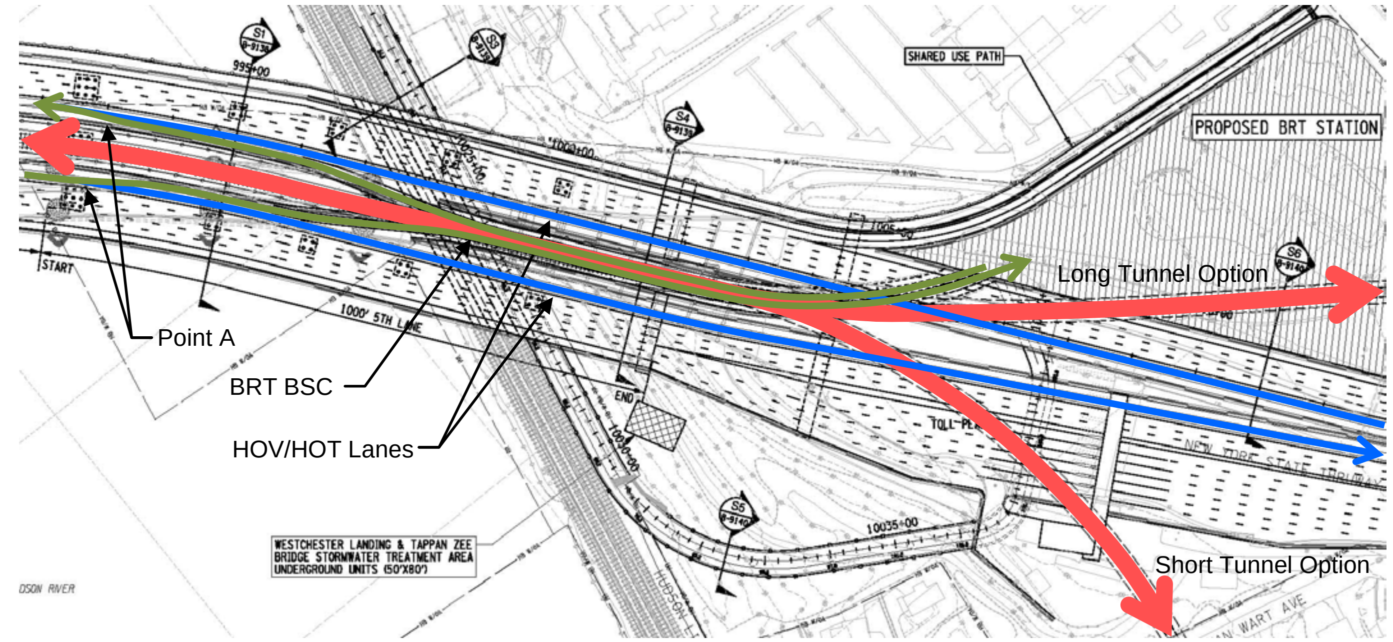


Figure 3.1 - Plan of Westchester Landing (Option 1)

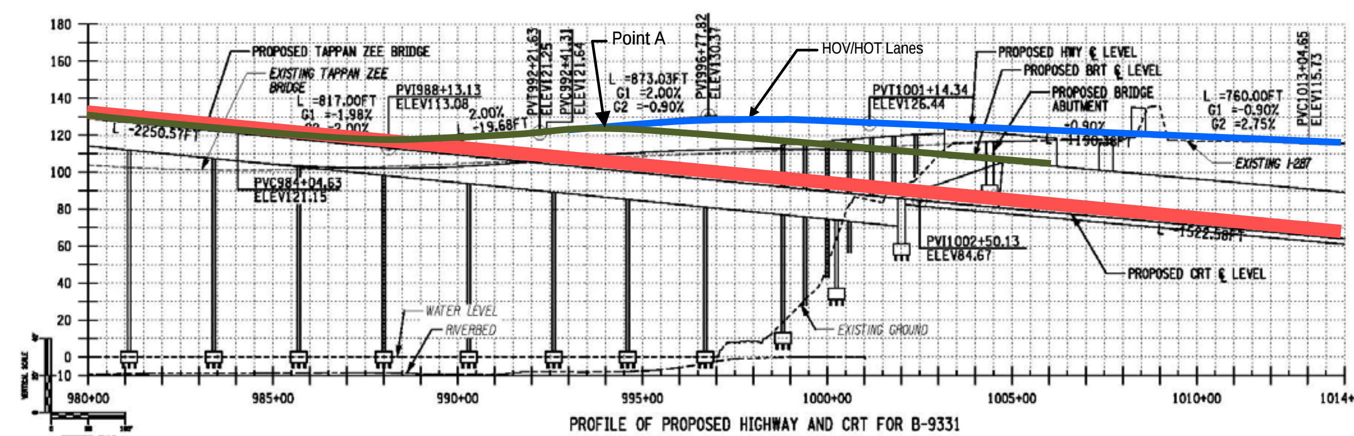


Figure 3.2 - Profile of Westchester Landing

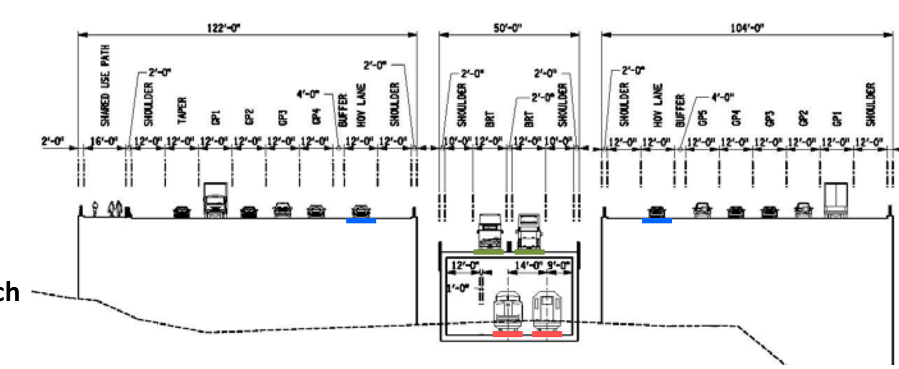


Figure 3.3 - Cross Section of Approach to Westchester Landing

3.3 Description of Options

3.3.1 Option 1 – Three Structures - CRT Center

This subchapter outlines the details of Single Level Option 1 to replace the TZB. The option is comprised of three new single-level structures. Two of these structures carry a typical directional BRT/HOV/HOT Highway lane arrangement. The third structure carries two tracks of CRT and an adjoining maintenance way. In Option 1, the CRT structure is located between the two BRT/Highway structures.

Replacement Bridge

Option 1 consists of three-column piers supporting three independent decks (Figure 3.4). The substructure will be steel piles driven into the river bottom capped by concrete pile caps upon which the pier columns stand. The superstructure consists of continuous hollow (but internally braced) concrete or steel decks that can be assembled from segments.

The superstructure form remains unchanged over the length of the crossing. The substructure transitions from the Rockland approach to three rows of columns supporting the decks at a common increasing height to a tower or arch supported Main Span. Past the Main Span, the Westchester approach returns to three rows of columns, their decks above descending together as they approach the shore.

Upon nearing the Westchester landing, the CRT continues to descend into the escarpment to reach the Hudson Line. However, the columns supporting the two highway/BRT decks become longer to enable the highway decks to reach the Toll Plaza and westbound lanes.

Landing Considerations

With all modal elements on the same level and greater space surrounding the CRT, Option 1 is the widest of the RTZB options at the Rockland landing. As the CRT approaches the Rockland shore, the maintenance way separates from the adjacent track and descends to enter the Dockside area. While the westbound highway/BRT deck would be immediately adjacent to the CRT, the eastbound deck would have a gap left by the descending CRT maintenance way. With the SUP and the Maintenance Access road directly underneath, the northern border directly follows the ROW. The southern border extends a minimum of 31 feet 8 inches beyond the ROW. A total of 13 displacements would be required.

Approaching the Westchester landing, the BRT separates from the highway lanes. Once adequate clearance over the CRT has been obtained, the two inside BRT lanes physically separate from the highway decks and come together in the center to form a two-way Y-shaped ramp structure. The highway decks continue to rise to reach the top of the escarpment. Meanwhile, the BRT ramps, collectively referred to as the Bridge Station Connector (BSC), follow atop the descending CRT while maintaining the required vertical clearance underneath. Upon reaching the escarpment, the descending BSC turns north under the westbound lanes to enter into the proposed Broadway BRT Station area north of the Thruway.

Construction Phasing Considerations

It is possible to phase construction of portions of the CRT system (Figure 3.5). For the RTZB, the CRT system consists of the substructure including piles, pile caps and columns, the superstructure which includes the deck, and the rail systems including track, power and signaling. At the landings, the substructure and superstructure transition to portals and continuing tunnels.

If construction of the CRT is phased, the arrangement of Option 1 requires that the CRT foundations be constructed concurrently with the substructure of the adjoining highway structures during the Initial Build (Figure 3.7). Pre-constructing the foundations is necessary to avoid unacceptable risks in driving new piles for the CRT between the completed highway structures. During the Initial Build, the CRT piles would be driven and the pile caps and columns constructed. In the Final Build, the superstructure would be constructed by means of a gantry, with infill of CRT deck through the Main Span, then subsequent installation of the trackwork.

The construction of the Rockland CRT portal and starting portion of the tunnel from the west can also be phased. This will require tight working between the constructed and operating highway lanes; however, access to this central area can be facilitated by pre-construction of a transverse accessway under the westbound highway lanes. This accessway would eventually connect the tunnel ventilation system to the CRT vent building located north of I-1287 in the vicinity of Interchange

At the Westchester landing, during the Initial Build it will be necessary to construct the BSC connection under the westbound lanes, and the tunnel box for either the Long HLC or the Short HLC under the respective westbound lanes or eastbound Toll Plaza.

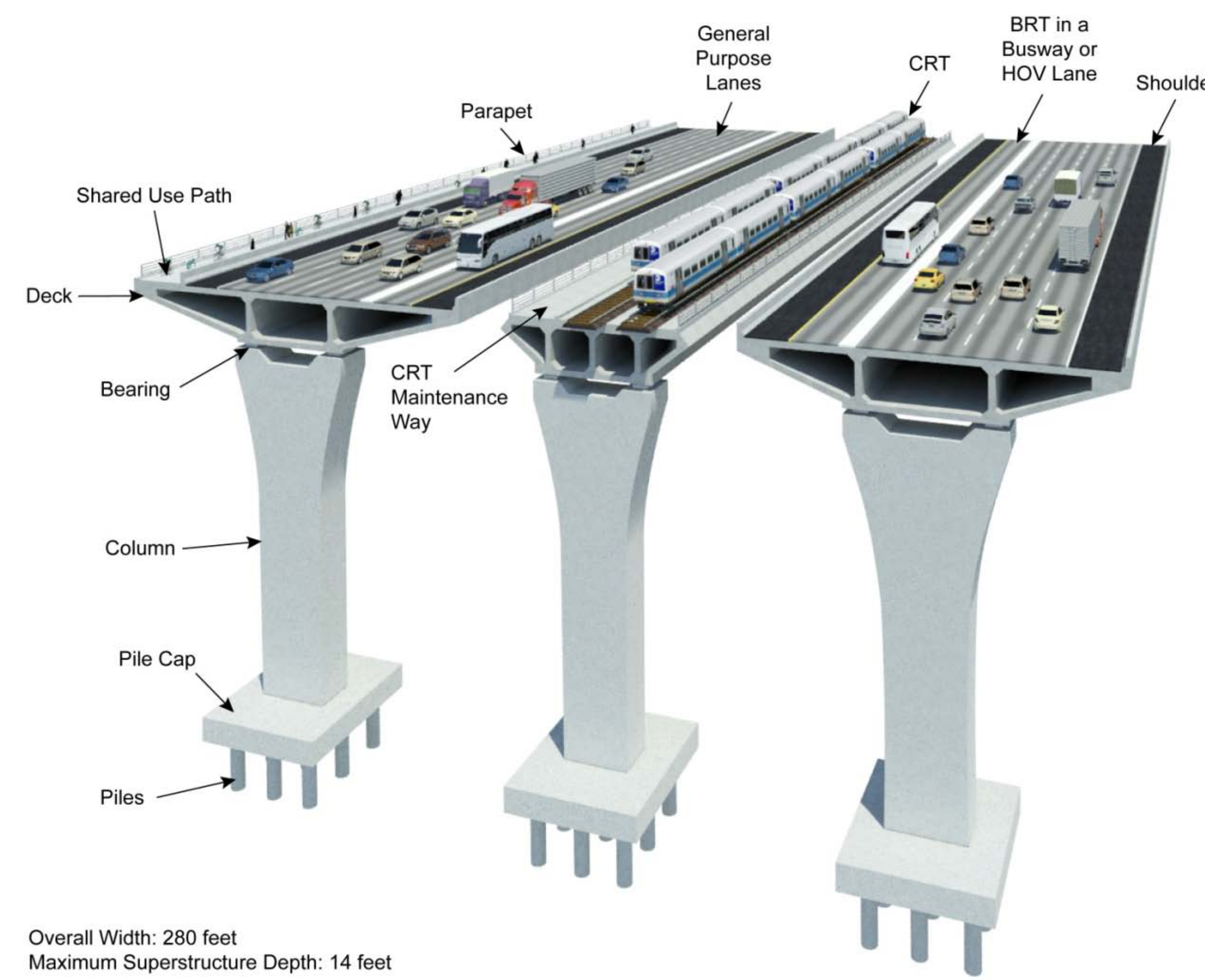


Figure 3.4 - Option 1 – Single Level CRT Center Three Structures

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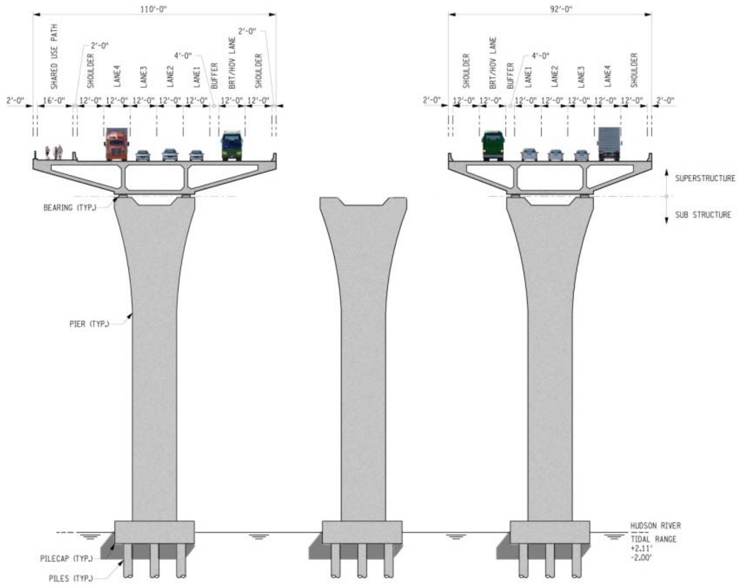
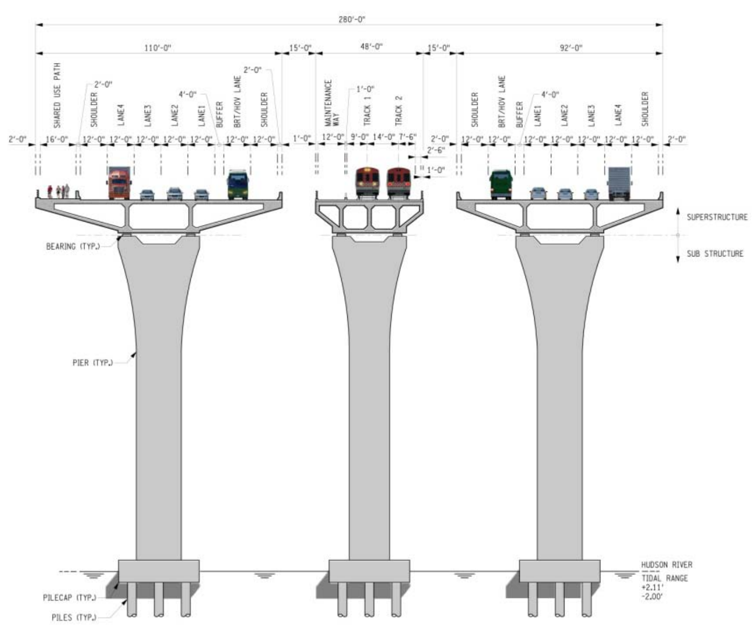
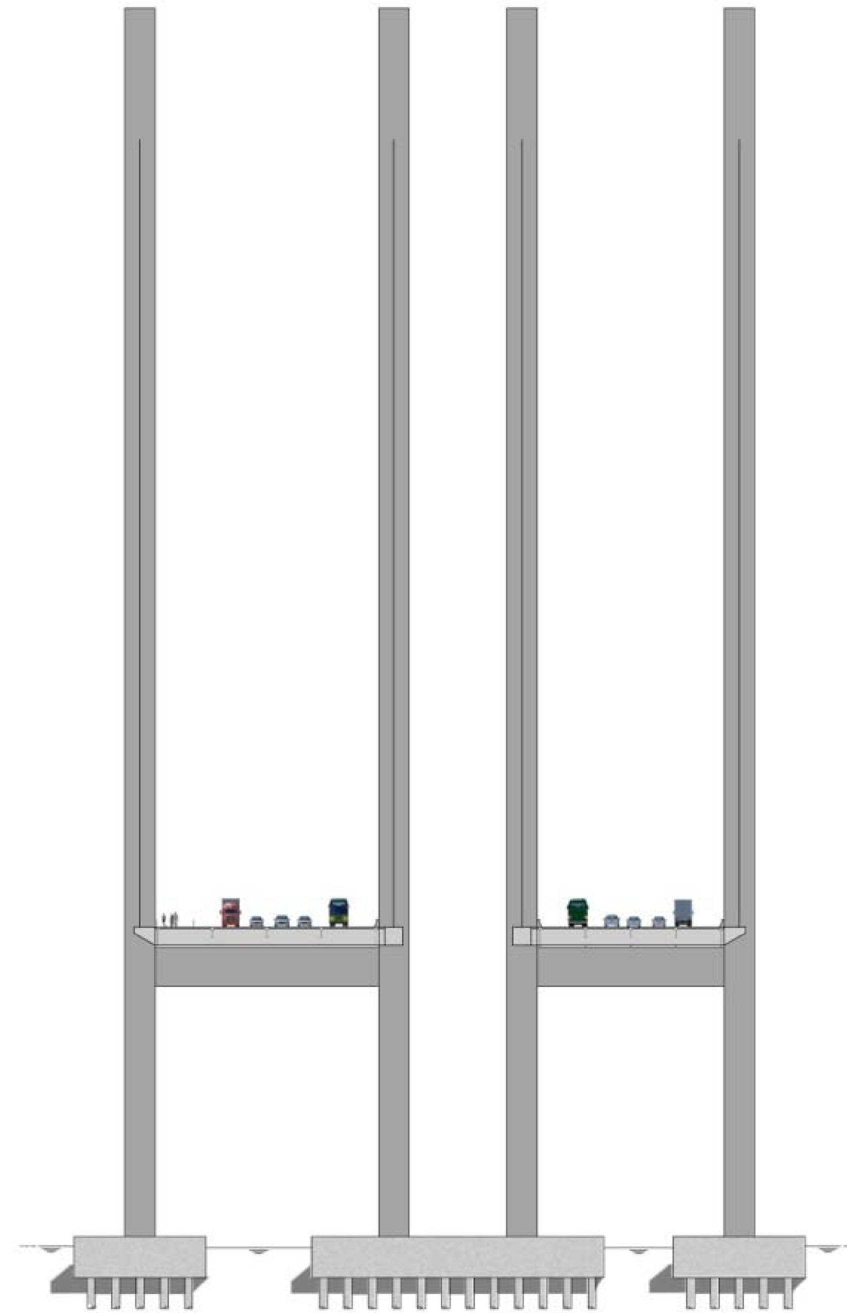


CRT Phasing Potential at Approach Span



CRT added in Final Build



Initial Bridge Configuration assuming CRT to be implemented at a later date

CRT added in Final Build

Approach Span

Main Span

Figure 3.5 - Option 1 Configurations

Full Build Cable Stayed Option at Main

Full Build Arch Option at Main Span

Figure 3.6 - Option 1 Main Span Options

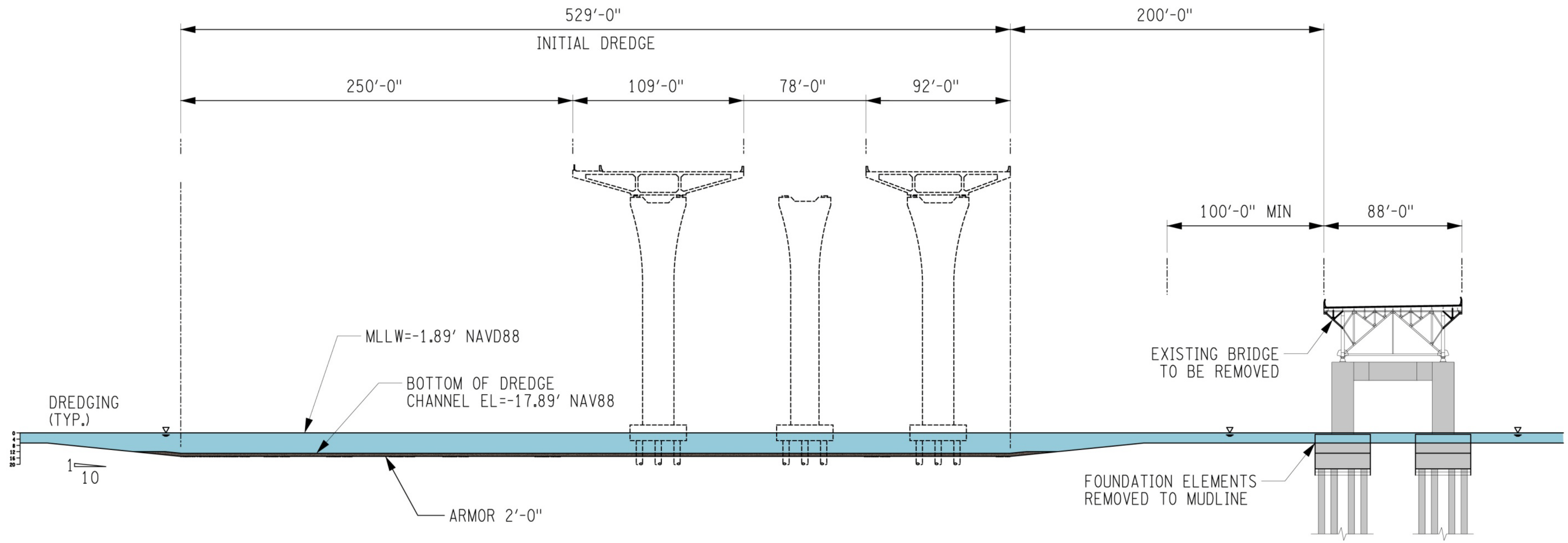


Figure 3.7 - Option 1 – Initial Build Dredging

3.3.2 Option 2 – Three Structures - CRT South

This subchapter outlines the details of Single Level Option 2 to replace the TZB. Similar to Option 1, this option is comprised of three single-level structures including two directional BRT/HOV/HOT Highway structures and a third two-track CRT structure with a maintenance way.

Due to options in when sub-structural elements of the CRT could be constructed, Option 2 has two variations: minimum CRT (where none of the CRT is constructed during the Initial Build construction phase), and minimum dredge (where CRT foundations and columns are constructed during Initial Build, and superstructure and CRT Main Span are constructed during Final Build).

Replacement Bridge

The structural form of Option 2 is identical to Option 1 with the exception that the CRT structure is located south of the BRT/Highway structures instead of between them (Figure 3.8).

Like Option 1, the crossing transitions from the Rockland approach with its three rows of columns supporting three independent decks at a common increasing height to a tower or arch supported Main Span. Because of the eccentricity of the rail loading, the Main Span would consist of two structures wherein one structure supports both BRT/Highway decks and a second independent structure supports the CRT. The Westchester approach reverts back to three decks supported on three rows of columns. Both the highway and CRT decks descend at the same grade, with the highway decks curving upwards as they approach the landing.

Landing Considerations

In Option 2, the development of the BSC is simpler and does not have to integrate with CRT below (as in Option 1). As a result, the final highway elevations can be lower coming into the Toll Plaza. The CRT, located south of the BRT/Highway decks, would enter the escarpment approximately 170 feet south of where it would have entered in Option 1.

While the three decks of Option 2 contain exactly the same elements as those of Option 1, the cross section at the Rockland landing is slightly narrower in overall width. The eastbound highway/BRT deck would be immediately adjacent to the westbound deck. The CRT deck would be immediately south of the eastbound deck and would consist of the CRT tracks only as the CRT maintenance way would drop down to River Road.

Approaching the Westchester landing, the development of the inside off and on ramps of the BSC will require the decks to be separated. Because the CRT is not directly under the BSC ramp, the ramp and the westbound highway lanes that will pass over the ramp can be at a lower elevation.

The CRT would enter the escarpment 170 feet south of that described for Option 1. At approximately elevation 86 feet, the CRT proceeds directly into a tunnel within the hillside.

Construction Phasing Considerations

If construction of CRT is phased, there are two options for how this can be accomplished with Option 2. The first is to minimize initial CRT construction. During the Initial Build, (should the Long HLC option be selected) only the tunnel box under the Toll Plaza and westbound lanes would be built. During Final Build, the CRT would be offset approximately 100 feet from the south highway structure to minimize the risk of installing piles adjacent to those supporting the completed highway deck (Figure 3.9). To provide access to construct the CRT, a second dredge prism of 0.90 mcy would be cut within and south of the CRT alignment (Figure 3.11 and Figure 3.12). This dredge prism would overlay a significant portion of the footprint of the removed TZB and would require additional efforts to remove residual TZB foundation elements. At the Rockland landing, the portal and start of tunnel structure would be constructed south of the reconstructed Thruway and Interchange 10 within a very narrow space bordered by very high retaining walls (Figure 3.15).

The other option is to construct the CRT substructure concurrently with that of the highway substructure, and complete the CRT superstructure later by use of a gantry, similar to the phasing for Option 1. During Initial Build, all CRT foundations including those of the CRT Main Span would be placed concurrently with the adjoining Highway/BRT foundations. The CRT foundations and columns would be constructed so the completed CRT structure is offset only 15 feet from the eastbound highway structure. To construct the towers of the CRT Main Span, dredging (0.52 mcy) to reestablish the accessway to a reconstructed Rockland temporary work platform would be required (Figure 3.13 and Figure 3.14).

During Initial Build, the Rockland portal and head of tunnel would be pre-constructed under the Interchange 10 eastbound ramps and highway while the eastbound highway is being reconstructed (Figure 3.16).

At the Westchester landing, it will be necessary during Initial Build to construct the BSC under the westbound lanes, and the tunnel box under the Toll Plaza and westbound lanes should the Long HSC be adopted. For the Short HLC, the tunnel box to support a possible cross-county connection would be constructed under the Toll Plaza and westbound lanes.

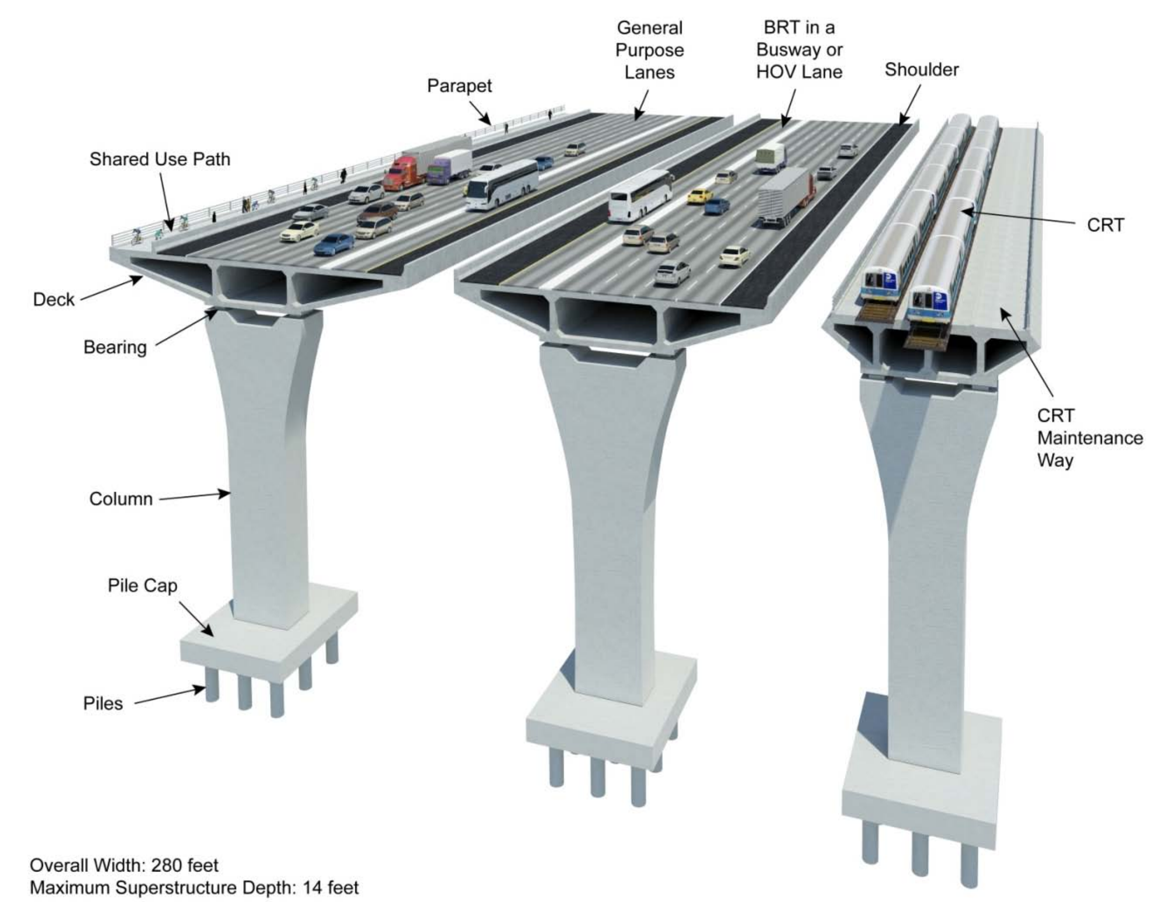


Figure 3.8 - Option 2 – Single Level CRT South Three Structures

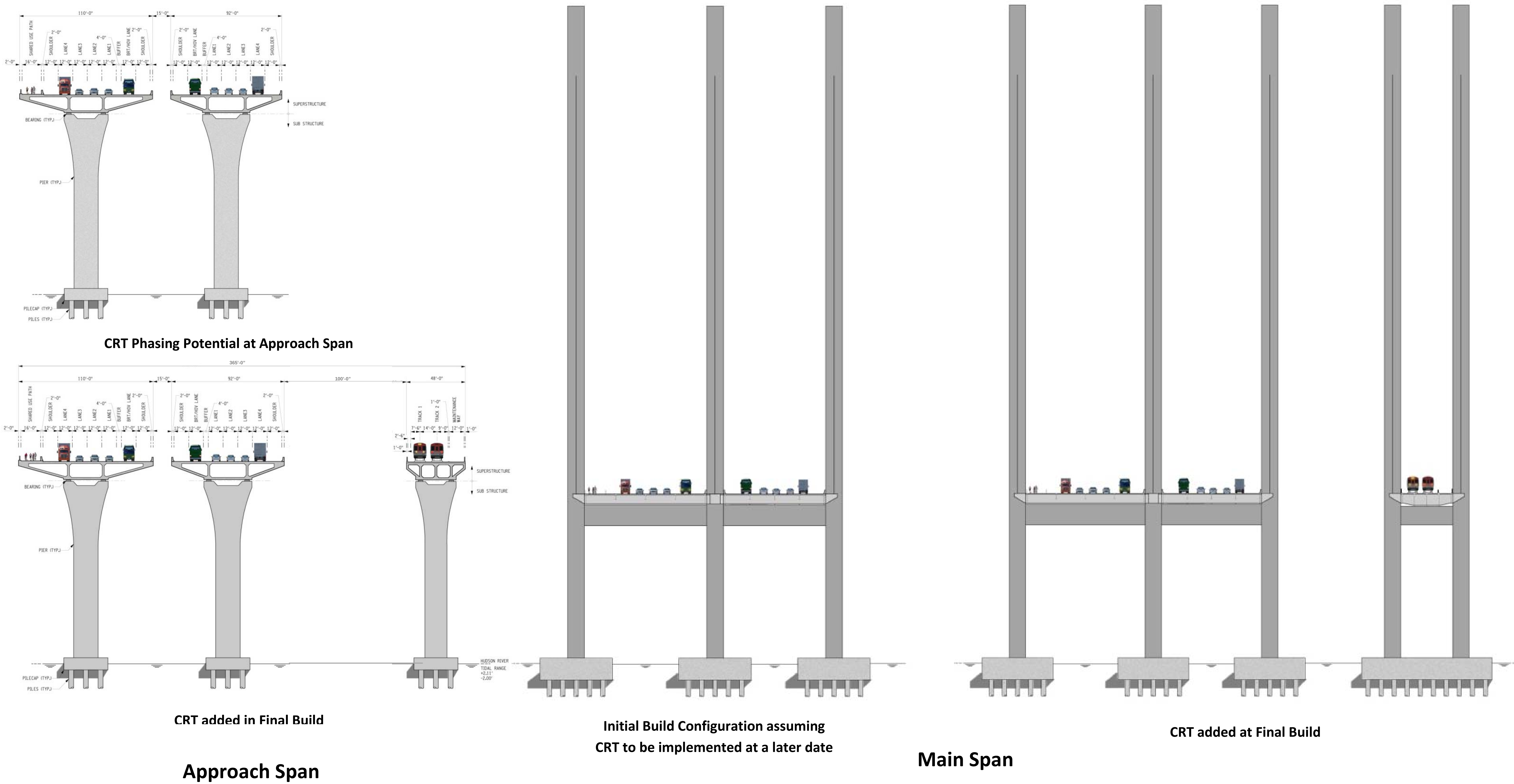


Figure 3.9 - Option 2 (minimum CRT variation) Configurations

Full Build Cable Stayed Option at Main Span

Full Build Arch Option at Main Span

Figure 3.10 - Option 2 Main Span Options

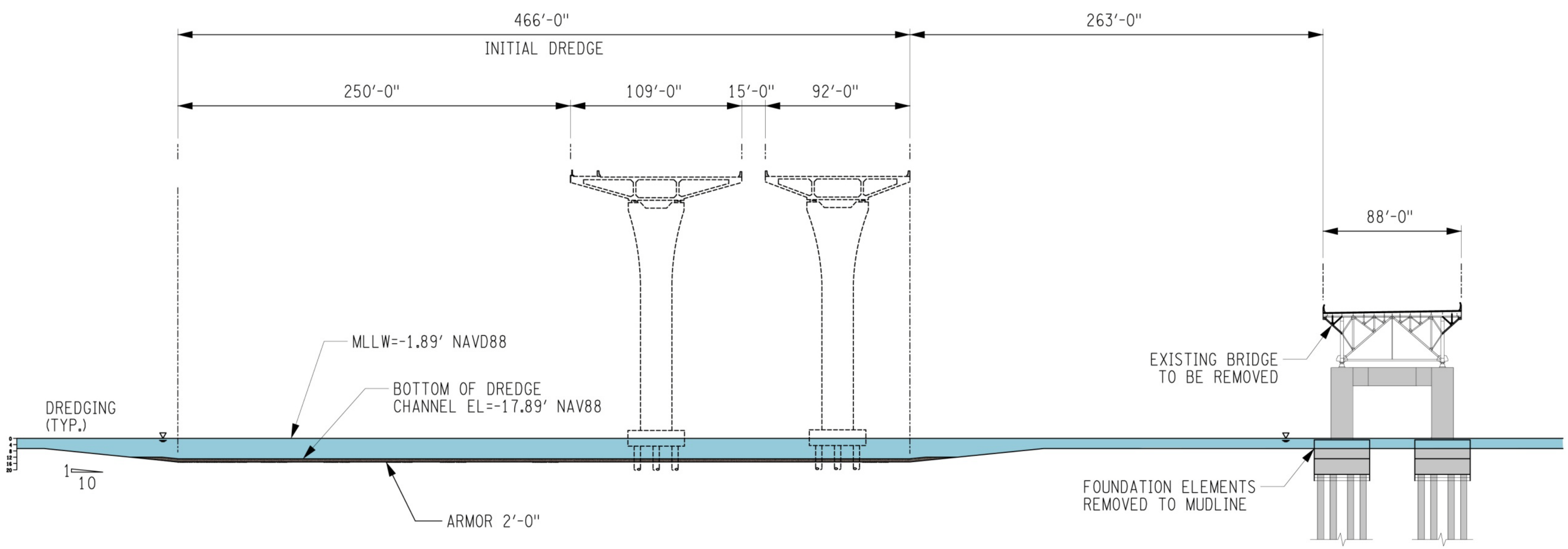


Figure 3.11 - Option 2 Minimum CRT - Initial Build Dredging

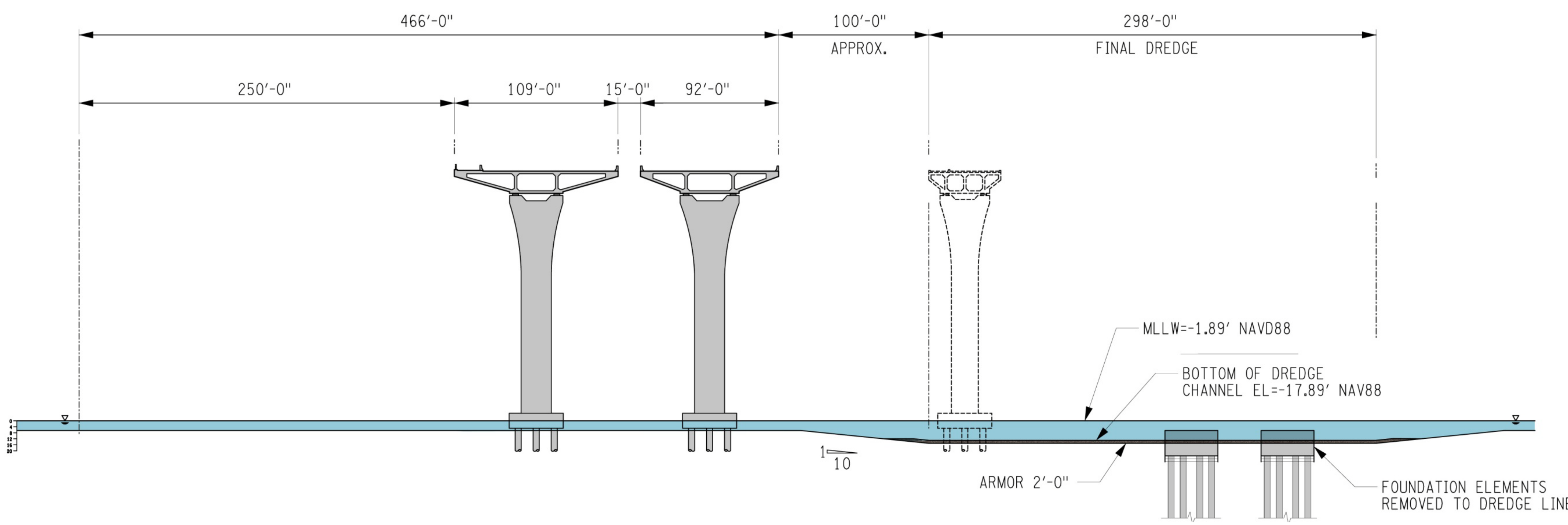


Figure 3.12 - Option 2 Minimum CRT - Final Build Dredging

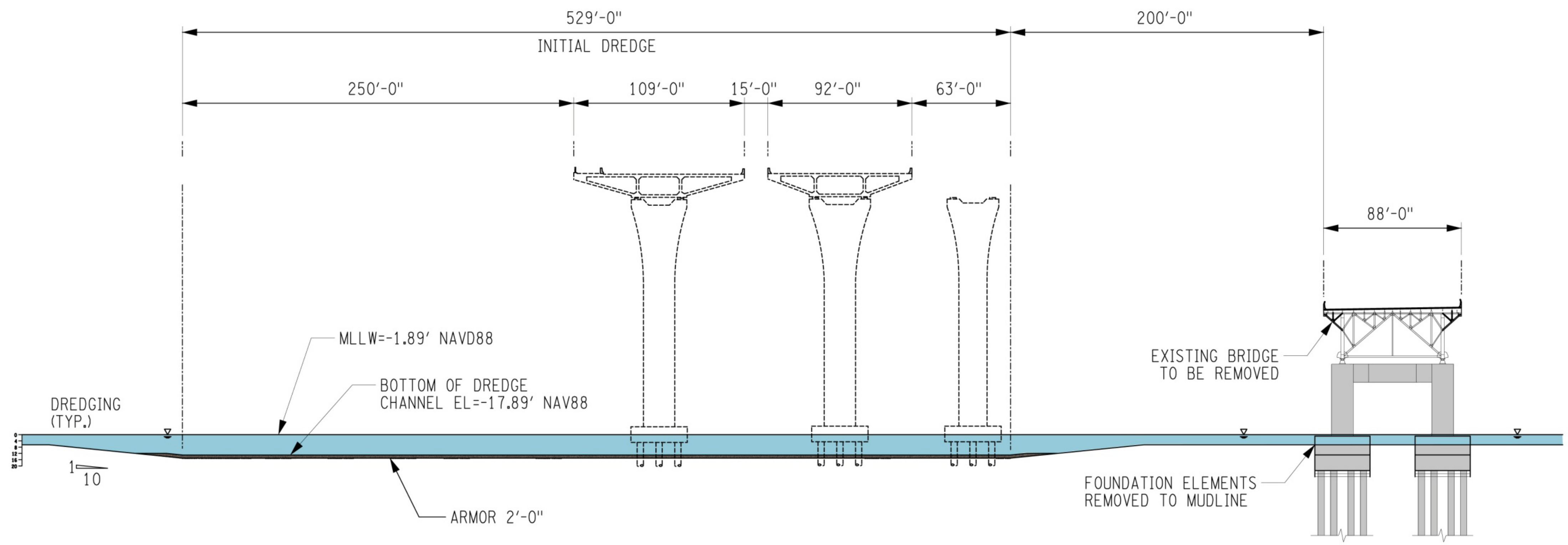


Figure 3.13 - Option 2 Minimum Dredge - Initial Build Dredging

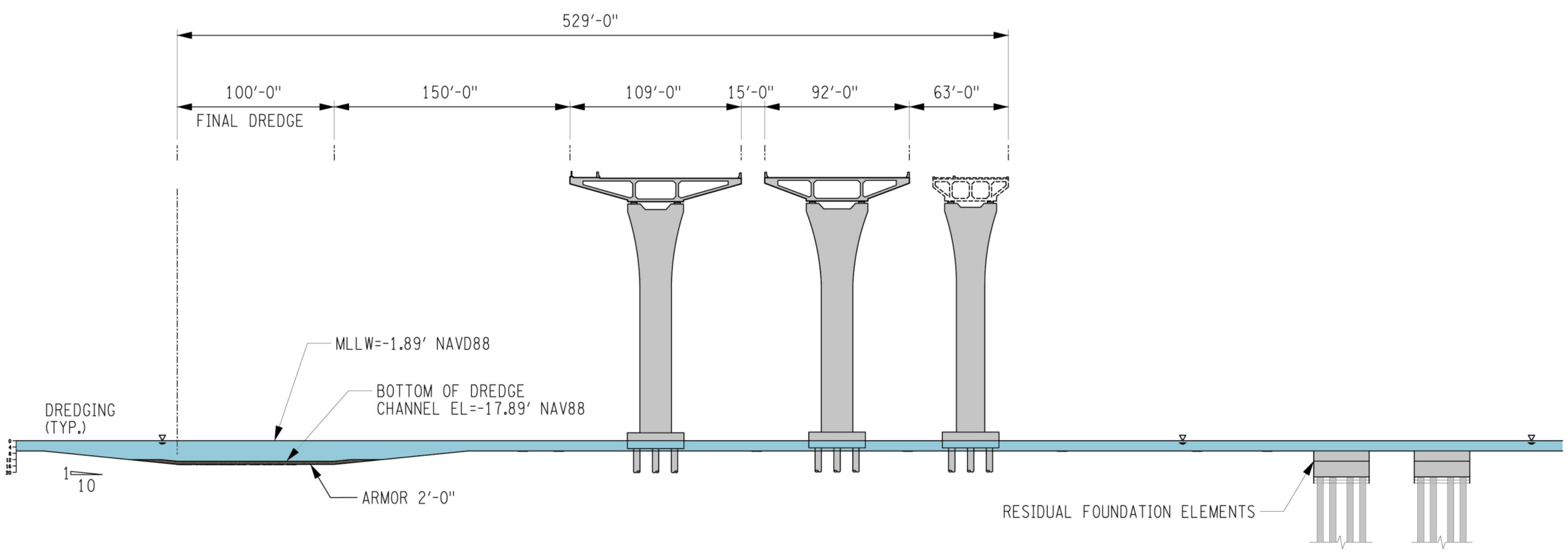


Figure 3.14 - Option 2 Minimum Dredge - Final Build Dredging

Figure 3.15 - Option 2 Minimum CRT - CRT Tunnel Alignment

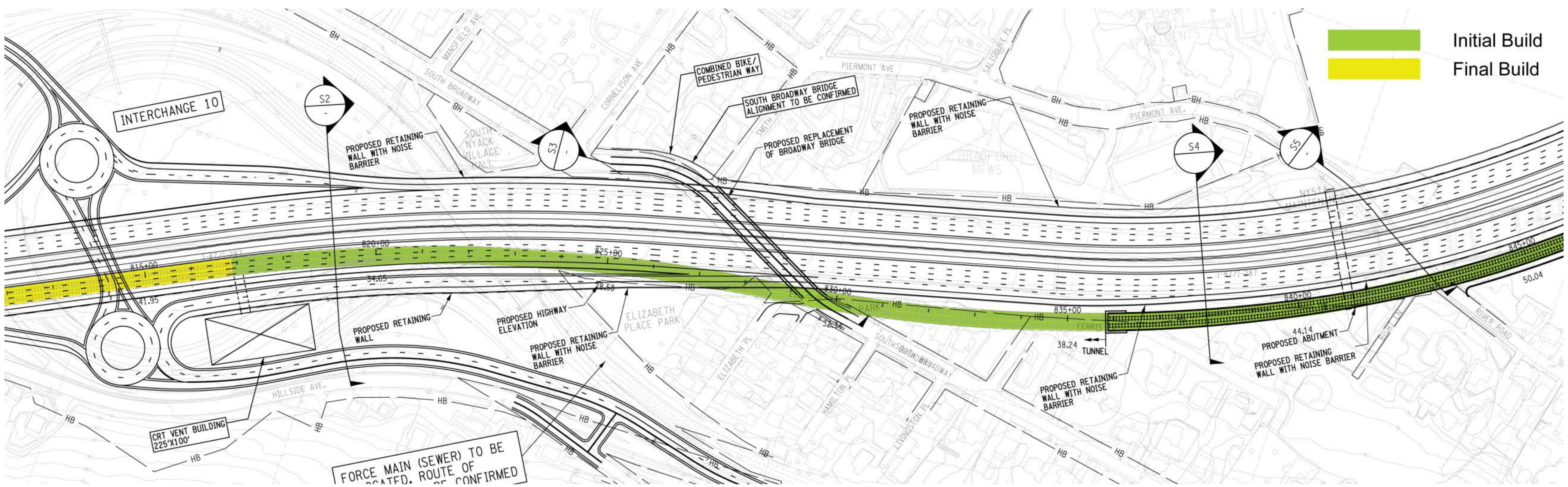


Figure 3.16 - Option 2 Minimum Dredge - CRT Tunnel Alignment

3.3.3 Option 3 – Two Columns – CRT Center

This subchapter outlines the details of Single Level Option 3 to replace the TZB. This option is similar to Option 1 with three single-level decks and with CRT in the center. However, instead of having three structures across the river, each supported by its own line of columns, this option supports its three decks on a single structure comprised of two columns and a crosshead beam.

Replacement Bridge

The superstructure form of Option 3 is similar to but narrower than Option 1, with three single-level decks and CRT in the center (Figure 3.17). This form is sustained across the length of the RTZB. To support the decks, the superstructure of the approaches consists of assembled bents. The elevation of the crosshead beam is determined by the profile required for the CRT. On the Rockland approach, similar to Options 1 and 2, the CRT would rise at the same rate as the highway lanes, on a straight line at a grade of 1.20% from the crossing of River Road, to the west tower of the Main Span. It is expected that the deck structure would transition at the back spans from the form used for the approach to a similar form over the back spans and Main Span. Again, similar to Options 1 and 2, the CRT and highway decks would descend from the Main Span towards Westchester at the same rate (approximately 1.96%).

Landing Considerations

At the Rockland approach, there is no difference between Option 3 and Option 1. At the Westchester approach, the only difference between Option 3 and Option 1 is the use of crosshead beams to support the CRT instead of an independent line of columns.

Construction Phasing Considerations

The bents consist of two columns each supported on a piles and a pile cap. The columns comprising the bent are centered under each of the outside highway spans. Until the CRT crosshead beam is constructed, the crossing consists of two BRT/highway structures on independent lines of columns. The initial construction for Option 3 would be identical with that of Option 1, with the exception that there is no center structure.

To create the final form of Option 3, the columns are transformed into bents by the addition of a crosshead beam between the columns (Figure 3.18). The crosshead beam could be pre-constructed and installed or cast in place. It is anticipated that this work could be completed from the constructed highway/BRT decks. Once placed, the crosshead beam and columns would be joined by post-tensioned tendons to create the frame action of the bent form.

Once the bents have been created, the CRT deck can be installed by gantry methods using post-tensioned segments. This structure has been identified to have less dredging compared to Options 1 and 2 because its overall width is narrower and requires no additional dredging to complete the CRT elements.

At the Rockland landing, similar issues attend the phased construction of the CRT portal and head of tunnel as Option 1. Like Option 1, it would be possible to make use of a pre-constructed passageway under the westbound lanes to provide access to the portal construction area from north of the highway. That passageway would eventually be converted to connect the tunnel ventilation system with the proposed Vent building at Interchange 10.

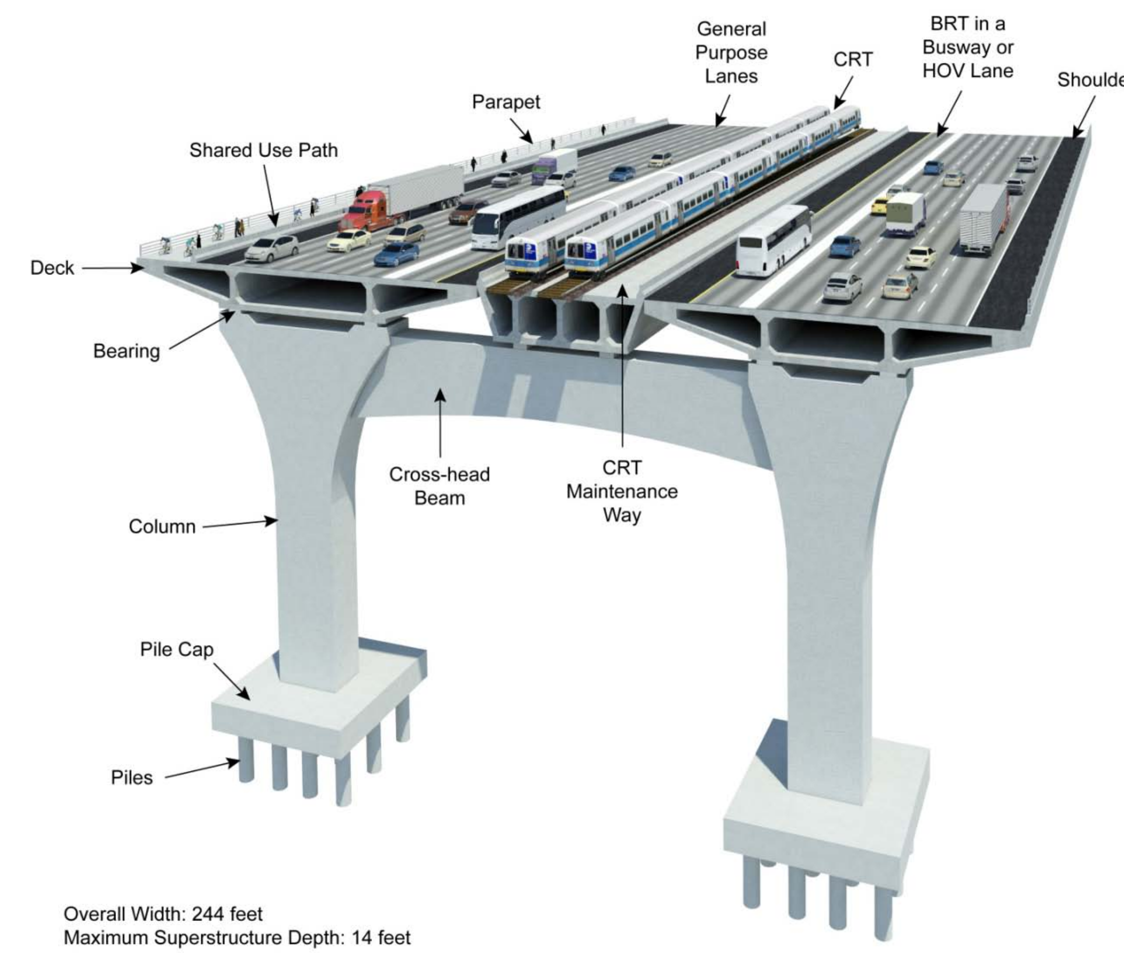
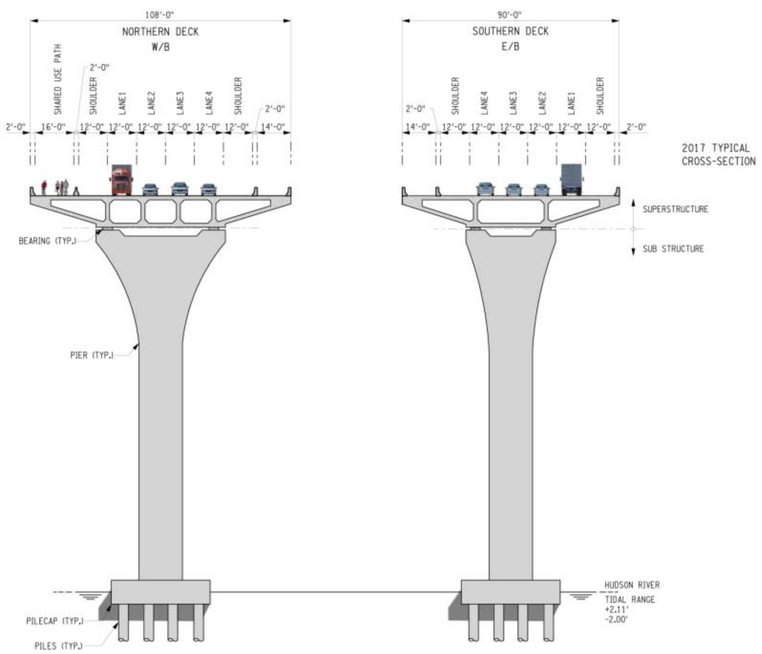
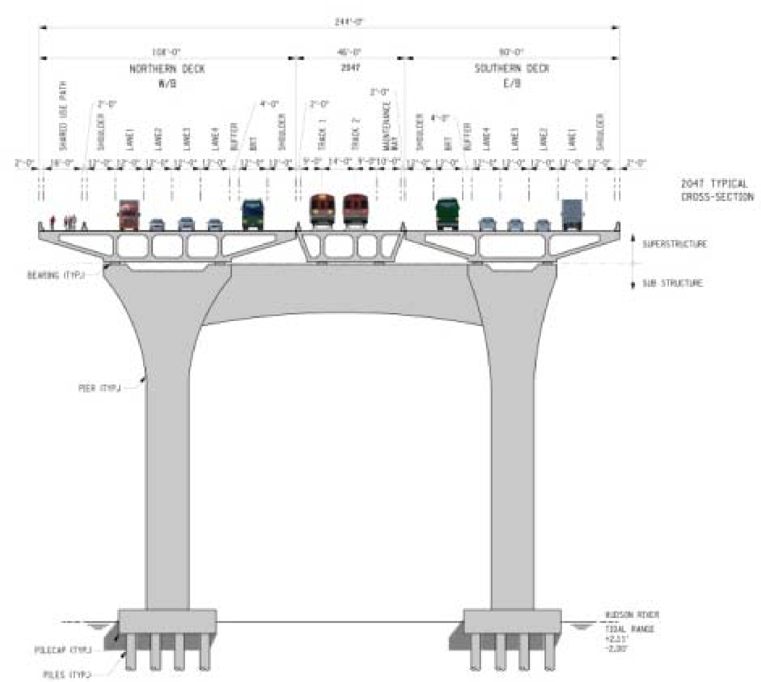


Figure 3.17 - Option 3 - Single Level CRT Center Two Structures



CRT Phasing Potential at Approach Span



CRT added in Final Build

CRT Phasing Potential at Main Span with CRT implemented at later date

Full Build Sections at Main Span

Approach Span

Main Span

Figure 3.18 - Option 3 Configurations

Full Build Cable Stayed Option at Main Span

Full Build Arch Option at Main Span

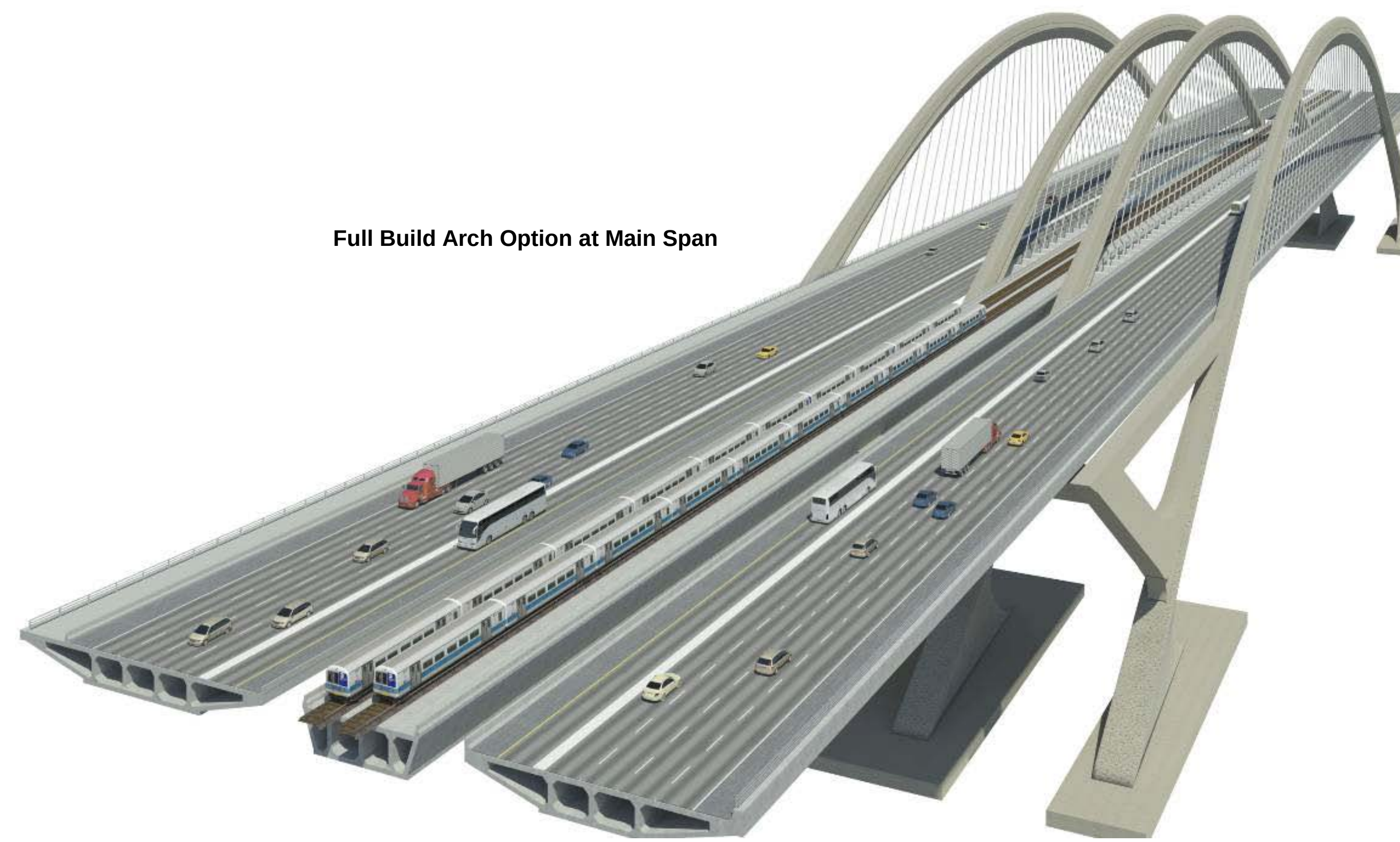


Figure 3.19 - Option 3 Main Span Options

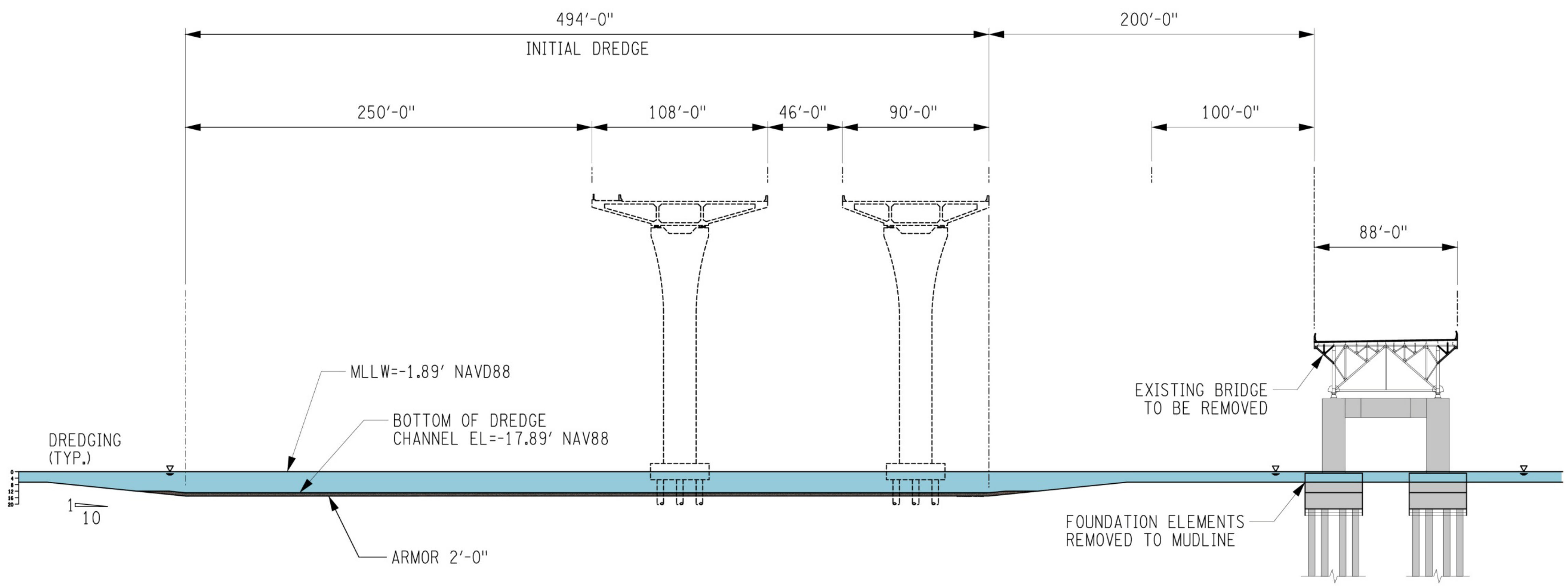


Figure 3.20 - Option 3 Initial Build Dredging

3.4 Engineering Evaluation

Engineering Criteria
Structural Integrity
Operations and Risk
Seismic
Redundancy
Emergency Response
Navigation
Life Span
Construction

This sub-chapter reviews three single-level options against the eight engineering criteria, each of which consider technical performance and compliance with codes, standards or agency requirements.

3.4.1 Structural Integrity

Structural integrity is the degree to which the RTZB options would be in compliance with current structural performance requirements. A service life of 150 years has been assumed.

Performance Requirements

The governing NYSDOT standards include the *NYSDOT LRFD Bridge Design Specification – US Customary 2007* (*LRFD Blue Pages*) and the *LRFD Bridge Design Specification, 4th ed.* from the American Association of State Highway and Transportation Officials (*AASHTO Design Specification*). The following excerpts from Chapter 1 in the *AASHTO Design Specification* outline the design philosophy that establishes the requirements for structural integrity:

> Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety and serviceability with due regard for economy and aesthetics.

Four limit states are identified including:

- **Service Limit State** – Restrictions on stress, deformation and crack widths
- **Fatigue and Fracture Limit State** – Restrictions on stress ranges due to repetitive traffic or train loading
- **Strength Limit State** – Strength and stability requirements to resist statistically significant load combinations that a bridge is expected to experience during its life span
- **Extreme Events Limit State** – Structural survival during extreme events including major earthquakes or floods or when impacted by a vessel, vehicle, or ice flow, possibly under scoured conditions

The requirements of the *AASHTO Design Specification* are minimum standards with applicability limited to bridge spans less than 500 feet. For longer span bridges, such as ther RTZB, project specific standards/specifications will be developed upon selection of a Main Span bridge type. These specifications typically include more stringent requirements than those required by the minimum standards set out in the *AASHTO Design Specification*. For the purposes of this report, the minimum standards outlined in *AASHTO Design Specification* are adopted.

Comparison of Options

Because the RTZB would be a new structure, all three single-level options would be designed to meet current code requirements. Nevertheless, there are noteworthy differences between the options that result in different internal structural actions, member sizes and overall structural performance that result in different material quantities, capital costs or maintenance requirements.

In the Approach Spans, all options have similar segmental box deck types with no notable difference in structural performance. Deck depths in all options are similar ranging from 8 feet at the mid span to 12 feet at the columns for the highway decks. Similarly, for the CRT decks, the depths are similar ranging from 10 feet at the mid spans to 14 feet at the columns. In all options the CRT deck is 2 feet deeper than the adjacent highway decks.

Table 3.1 presents the primary substructure components of the three single-level options. Note that two variations are depicted for Option 2, a Minimum CRT version, and a Minimum Dredge version. As will be discussed further in section 3.4.8 on page 37, portions of the CRT construction can be phased for all options. To paraphrase that discussion, during Initial Build, the piles and columns for the CRT structure would be constructed for Option 1 and Option 2 – Minimum Dredge. For Option 2 – Minimum CRT, nothing of the CRT structure would be constructed during Initial Build. During Final Build, the CRT substructure elements (quantities expressed in parentheses in Table 3.1) and superstructure elements would be constructed.

The 122 columns required for Option 3 are substantially less than the 183 required in Options 1 and 2. While the columns in Option 3 are larger in section than the other options, the lesser number of columns results in fewer construction activities leading to reduced construction costs and duration, as well as reduced maintenance and inspection requirements.

At the Main Spans, the depth of the structural decks for all the options is similar at 9 feet and 11 feet for the respective highway and CRT decks. However, the required number of tower legs or pylons differs between options (Table 3.1). Options 1 and 3 utilize 8 tower legs, with legs located between and on either side of all decks. For Option 2, 10 tower legs are utilized as the CRT deck structure is separated from the highway structure to avoid undesirable torsional actions in the highway decks.

In Options 1 and 2, all vertical loads from the superstructure in the approach spans are carried directly down to the foundations via columns. In Option 3, the vertical loads from the CRT deck structure are passed to the foundations via a transfer crosshead beam. While the crosshead beam is a typical element in many bridges, consideration of Fatigue and Fracture Limit State (crack formation under repetitive loading) is warranted. Assessment of the fatigue condition indicates that the stress range resulting from CRT loading is not significant and would not affect the life span of the structure. Post-tensioning of the crosshead beam would be required to relieve tension conditions in the crosshead and provide added redundancy.

In Options 1 and 2, the columns act as simple cantilevers to resist applied lateral loads from wind and seismic conditions; however, in Option 3 the crosshead beam generates a framing action with the columns that reduces the overall demands on the foundations. The approach spans of Option 3 benefit from both reduced dead load (the crosshead beams and strengthened outside columns replace the heavier center pile caps and columns) and greater stiffness to resist lateral forces through the framing action generated by the crosshead beam. In Option 3, the reduced dead load and improved structural behavior after CRT is constructed enable an 11-13% reduction in the number of piles and foundation sizes compared to Options 1 and 2.

	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Number of Columns	183	122 (61)	183	122
Number of In-River Columns	168	112 (56)	168	112
Number of Tower Legs	8	6 (4)	10	8
Number of Piles	2300	1550 (800)	2350	2043
Number of In-River Piles	2216	1494 (772)	2266	1968

Table 3.1 - Initial Build and (Final Build) Primary Substructure Components of Single Level Options

Overall, all three single-level options are feasible. Options 1 and 3 have more efficient Main Span structures as live loading is symmetrical and have fewer towers than Option 2. Option 3 has 33% fewer columns in the Hudson River and has 11-13% fewer piles than the other two options.

3.4.2 Operations and Risk Assessment

The measure for this criterion is the performance of the RTZB in Normal, Natural, Accidental, and Intentional event scenarios. The objective is to identify those event scenarios where performance would differ between the options. Details of the 102 event scenarios considered are presented in Table C1 in Appendix C (not included in this report), with specific event scenarios ranging from the effects of wind on trucks or trains to the effect of intentional attacks on specific components of the bridge structure. The following highlights the more significant event scenarios and their implications.

Normal Events

Of the 24 events considered (events 6-29 in Table E1) differences between options were identified in only 3 events. In general, the presence of the maintenance way adjacent to the CRT tracks limited interaction between CRT and Highway operations, maintenance and repairs. The differentiating events included:

Event 15: Highway access between westbound and eastbound directions

In this event Option 2 was advantageous as access through the median for maintenance or security personnel would be unimpeded by the CRT. For Options 1 & 3, temporary structures between the south and north structures to provide access between the eastbound and westbound lanes would be installed during Initial Build for use until the CRT is constructed during Final Build. Once the CRT is constructed in Options 1 and 3,temporary suspension of CRT service would be required before vehicles could cross the median. Emergency and operational procedures would be developed between the agencies ensuring turnarounds. In normal operations, the inability to cross the median while on the RTZB is not considered significant.

Event 17: Foundation and column repair and maintenance in the Approach Spans

In this event, the fewer number of columns in Option 3 compared to Options 1 and 2 was advantageous as it would result in reduced duration and cost for inspection and repair of the columns and pile caps.

Event 29: Cable inspection and repair in the Main Spans

In Option 2, the inability of maintenance and equipment vehicles to either cross or use the CRT tracks to immediately access adjacent to both lines of cables on the Main Span CRT structure was registered as a disadvantage. Though the maintenance way on the CRT structure would provide vehicular access to the southern line of cables no direct access would be possible to the northern line of cables. Access to these cables would likely require temporary suspension of the CRT service.

Natural Events

Of the 12 events considered (see events 30-41 in Table E1) differences between options were identified only in 2 events. The differentiating events included:

Event 31: Wind on CRT Vehicles

While all options would be subject to similar wind forces, the CRT structure located south of the Main Span in Option 2 would be subject to local eddies generated by the interaction of the wind and the Main Span. Further, the Hudson River valley is known to generate substantial local wind gusts. As a consequence, wind speed trigger levels for CRT speed restrictions or service suspension may be lower for Option 2 than for the other options. Passenger discomfort under less severe wind conditions may also be more noticeable.

Event 41: Substrate Settlement

In the area of the deep soft soils on the western side of the Hudson River, substrate settlement of up to 10 inches is expected over the life of the RTZB. These settlement rates do not differ substantially across the options as the pressures at depth are comparable for the various founding arrangements. Fifty percent of the total settlement is expected to occur in the first 10 years after construction and the remainder over the life of the bridge. The ability to jack up and reposition the highway and CRT will be needed in all options to counter differential longitudinal settlements.

Because of the crosshead connection between the two highways decks in Option 3, each two-column bent may be subjected transverse differential settlements. These are expected to be small as the founding layers do not vary substantially in the transverse direction. Later in the design process, when further geotechnical information is available, specific predictions of transverse differential settlements will need to be made. Pending this level of detail, the deep crosshead beam included in Option 3 would be designed to accommodate the secondary load sharing that would occur. This crosshead would function in a similar manner to the crosshead in the existing Causeway that also acts to limit differential settlement.

Accidental Events

Of the 46 events considered (see events 42-77 in Table E1) differences between options were identified in 5 events, all associated with CRT derailment or fire. The differentiating events included:

Events 60, 61, 62, 63: Derailment of CRT or maintenance train in the Approach or Main Spans

These events have in common the train derailment differing only in the type of train or location. In these events all options have in common low-level containment walls to limit off track movements. However, the potential for trains to cross the containment walls cannot be eliminated and in all options secondary containment walls in the form of jersey barriers or similar would further contain derailment.

Beyond the effectiveness of these containment devices any derailed trains in Option 3 that cross the jersey barrier would most likely be contained within the highway deck. In Options 1 and 2 any train that crossed the jersey barrier would fall into the Hudson River.

Event 74: CRT train fire

No difference between options in terms of impact of fire on structure was identified. However, the options differed in access for emergency responders. In Options 1 and 3 emergency responders would access the incident from both Thruway directions. Access for Option 2 would be from the eastbound lanes only.

Intentional Events

Of the 25 events considered (see events 78-102 in Table E1) differences between options were identified in 2 events associated with improvised explosive devices (IED). The implications of these events were similar to Event 74 identified already.

Overall, 12 events resulted in differences between options of which only: differences in emergency response, potential implications to CRT services due to wind condition, and maintenance access to cables are considered significant. All of these differences favor Option 1 or Option 3 with Option 2 being the least favored as CRT is isolated away from access or protection.

3.4.3 Seismic

The seismicity criterion is a measure of the seismic performance of the RTZB. As a ‘critical’ piece of infrastructure the TZB is required to meet the following performance levels:

- **Functional Event**: After a moderate seismic event the TZB should suffer no damage to primary members and be open for traffic within hours. A moderate event is defined as an earthquake with an approximate 500-year return period.
- **Safety Event**: After a major seismic event the TZB should have repairable damage and be open to emergency services within 48 hours and to general traffic within months. A major seismic event is defined as an earthquake with an approximate 2500-year return period.

All three options can meet these performance requirements with no major differences. The only differences between the options are the resulting member and foundation sizes which are accounted for in the capital cost estimates.

3.4.4 Redundancy

Redundancy is a measure of the ability of a service element to fulfill its function by secondary means after its primary functional mechanism is incapacitated. For the TZB, two aspects of its redundancy have been important and form the basis for the evaluation of redundancy criterion in previous technical reports: its capacity after an event and the time required to permanently restore previous capacity. These aspects, however, were more appropriate when considering the rehabilitation options in previous reports as sufficient redundancy was not present.

For the new replacement RTZB, the provision of adequate redundancy is inherent in the design process from the outset. As such, the provision of redundancy is only one of a number of options available to ensure adequate safeguards against possible event scenarios within an overall risk reduction framework. Other measures that reduce risk include strengthening, offsets and the provision of protection, for example, ship protection around piers. Where necessary redundancy can be provided in the form of additional post-tensioning cables within box girder decks, or spare cable capacity in the main spans, or secondary local load paths in steel connections.

The outcome of this overall risk reduction strategy, of which redundancy is just one part, would be a uniform level of risk across the Single Level Options.

3.4.5 Emergency Response

Provision for emergency response would be included in all options including standpipe facilities and appropriate means to fight train electrical fires. Detailed emergency response plans would be developed in the course of final design and coordinated with the appropriate authorities based upon industry best practice. This criterion focuses on the ability of emergency services to access emergency events.

In all three Single Level Options access to the highway and CRT decks would be via the Thruway. Should traffic be congested on the bridge as a result of an auto accident, access for emergency vehicles would be available along any of the traffic shoulders.

In Options 1 and 3, access to the central CRT structure for emergency vehicles would be possible from both directions on the Thruway. In Option 1, direct access to the CRT deck would be provided at discrete locations, possibly at intervals of 200-400 feet. At these locations, permanent controlled access foot bridges between the CRT and highway structures would allow emergency personnel to walk between structures. In Option 3, controlled gated access between the CRT and both immediately adjacent highway structures would be provided at frequent intervals (e.g., every 100 or 200 feet).

In Option 2, access for emergency vehicles to the CRT structure would be along the inner shoulder of the eastbound lanes. Similar to Option 1, controlled access footbridges would be provided between the CRT and adjacent highway structures at intervals of 200-400 feet.

Overall, Option 3 maximizes CRT emergency response access.

3.4.6 Navigation

The measure for this criterion is the level of conformance to navigational requirements of the US Coast Guard, who currently control the 600-foot wide and 139-foot high channel for shipping under the TZB. All Options would accommodate these minimum dimensions for shipping.

At this stage in the Environmental Review process, the US Coast Guard has not changed these dimensional requirements but initial discussions indicate that some ships using the channel lower their uppermost equipment to pass under the TZB. Because a replacement bridge is proposed, initial indication from the US Coast Guard is that an increase in the vertical clearance would be preferred, possibly to that of the Bear Mountain Bridge (155 feet), the next lowest clearance on the Hudson River. All options would provide the 155-foot vertical clearance.

3.4.7 Life Span

The life span of bridges is a function of the life span of their components, including steelwork, joints and bearings among others. No component lasts forever. Life spans can range from as low as 5-10 years for some types of deck joints to up to 100 years for steelwork and concrete that is adequately protected. To ensure a long life span for a bridge, a full program of maintenance, repair and replacement is necessary based on component inspections and expectations. As such, the life span of a bridge is the decision of the owner/operating agency that controls the maintenance regime. However, as bridges age, the rate of component repair and replacement can be unsustainable with extensive maintenance activities affecting overall traffic operation.

The current *AASHTO Design Specification* for highway bridges references a 75-year life span for standard bridges. For bridges of the scale of the TZB, the owner agency would be expected to prepare a life cycle plan. This plan would include a cost-benefit analysis for the various components and their expected life spans. Among the operating criteria established by the NYSTA, the owner operator of the TZB, is the requirement for no major component replacement in the first 100 years in any of the Replacement Options. For the purposes of this report, maintenance and repair programs as well as consequent costs for each option have been assumed to sustain the various crossing forms for 150 years.

One particular area of concern for the Single Level Options is the durability of the concrete box girder deck particularly if the top of the girder is used as the roadway surface. Later in the design process, a full life-cycle plan is required to determine the number and extent of protection layers to be applied to the deck to minimize whole life expenditure.

3.4.8 Construction

This criterion identifies the type, scale and duration of construction and the potential phasing of CRT in line with the Tiering process for transit.

Construction Type and Scale

Options 1-3 are each of similar type and scale of construction. Each option incorporates the same type of piles, columns and deck structure and differs only in the number of components. Table 3.2 summarizes the volume of dredging and the area of river bottom affected by dredging, which differs significantly for the two versions of Option 2.

Construction Duration

The construction sequence for all options follows the same basic steps. Construction initially commences in the deeper water near the main Hudson River channel and from there progresses towards both landings. As shown in Figure 3.21 the overall duration of construction for Options 1 and 2 is similar at approximately 5½ years, while construction duration for Option 3 is approximately six months shorter largely due to the 33% fewer columns in this option.

	Dredge Parameters			
	Option 1	Option 2 minimum dredging	Option 2 minimum CRT	Option 3
Structure width (feet)	280	280	365	244
Access channel width (feet)	250	250	250	250
Dredge width (feet)	530	530	865	494
Full Build Dredge volume (mcy)	1.77	-	-	1.65
Initial Build Dredge volume (mcy)	-	1.77	1.58	-
Final Build Dredge volume (mcy)	-	0.52	0.90	-
Phased total Dredge volume (mcy)	-	2.29	2.48	-
Area dredged (acres)	166	166	256	155

mcy – million cubic yards

Table 3.2 - Dredging Parameters for Single Level Options

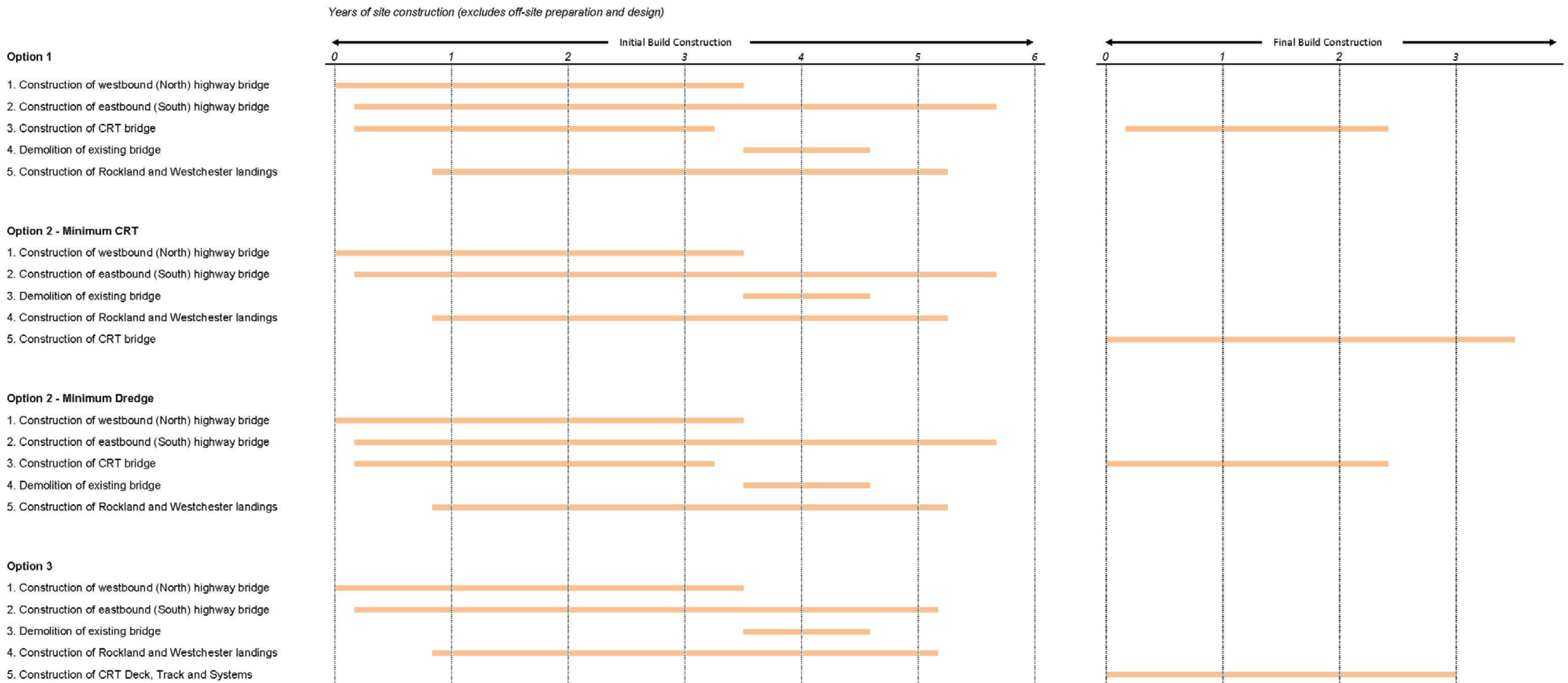


Figure 3.21 – Initial Build and Final Build Construction Duration for Single Level Options`

CRT Phasing

Figure 3.22 shows the CRT phasing potential for Options 1-3 for the typical Approach Spans. For each option, only the structure necessary to implement the highway and BRT lanes would be initially constructed along with any other structural components that would be difficult/expensive to construct it at a later date.

For Option 1, because of the difficulty in later placing the piles and constructing the central columns that support the phased CRT, it would be necessary to build the central substructure (piles, pile caps and columns) as part of the initial highway construction. All dredging (1.77 mcy, $65m)) would be completed as part of the Initial Build highway construction. Subsequent Final Build construction of the CRT approach deck would use gantry methods with segment delivery from the adjoining highway spans. The gap between the highway Main Spans would be filled with CRT deck. This deck would be supported on transverse girders tied into the adjoining highway/BRT supporting columns. All subsequent CRT construction material would be delivered from the highway lanes.

For Option 2, two approches to phase the CRT construction are possible. The first minimizes the total dredging required and similar to Option 1, constructs the substructure for the CRT at the same time the highway substructure is constructed. This allows the CRT structure to be relatively close to the south highway structure, a safety benefit. Like Option 1, the CRT approach deck would be constructed using gantry methods with segment delivery from the adjoining eastbound shoulder. Because the Main Span for the CRT would be constructed during the final build phase, it would still be necessary to re-dredge an access channel from the Rockland shore to deliver material to construct the CRT Main Span. Dredging under this approach is estimated at 1.77 mcy ($65m) during Initial Build, with an additional Final Build dredging of 0.52 mcy ($19m) to enable access to consruct the CRT Main Span, for a total of 2.29 mcy ($84m).

The second approach for Option 2 is to minimize all CRT construction. To reduce the risks of either accidents or disturbance of already placed foundations during the installation of the piles, the CRT structure would be offset 100 feet from the south edge of the eastbound highway/BRT structure. This approach would require two full rounds of dredging. The Final Build dredging would partially overlay the wood pile foundations from the demolished TZB, which may result in increased effort. Dredging under this approach is estimated at 1.58 mcy ($58m) initially and 0.90 mcy ($33m) during Final Build to construct all the CRT structure, for a total of 2.48 mcy ($91m). For both construction approaches, much of the second round of dredging will be recent redeposited material which may be contaminated, thus it is anticipated that up to half of the material extracted may not be suitable for ocean disposal and would require significantly more expensive upland disposal.

Option 3 with its two columns requires only an initial round of dredging (1.67 mcy, $61m) with no further construction in the Hudson River to complete the CRT. When CRT is implemented during Final Build, the crosshead beam between the columns can be constructed from the adjoining highway/BRT decks. The CRT deck can be constructed using gantry methods with segment delivery, also from the adjoining highway/BRT decks. Like Option 1, the gap between Main Span highway/BRT decks would be filled with CRT deck supported on transverse girders tied into the adjoining highway spans. No further dredging would be required.

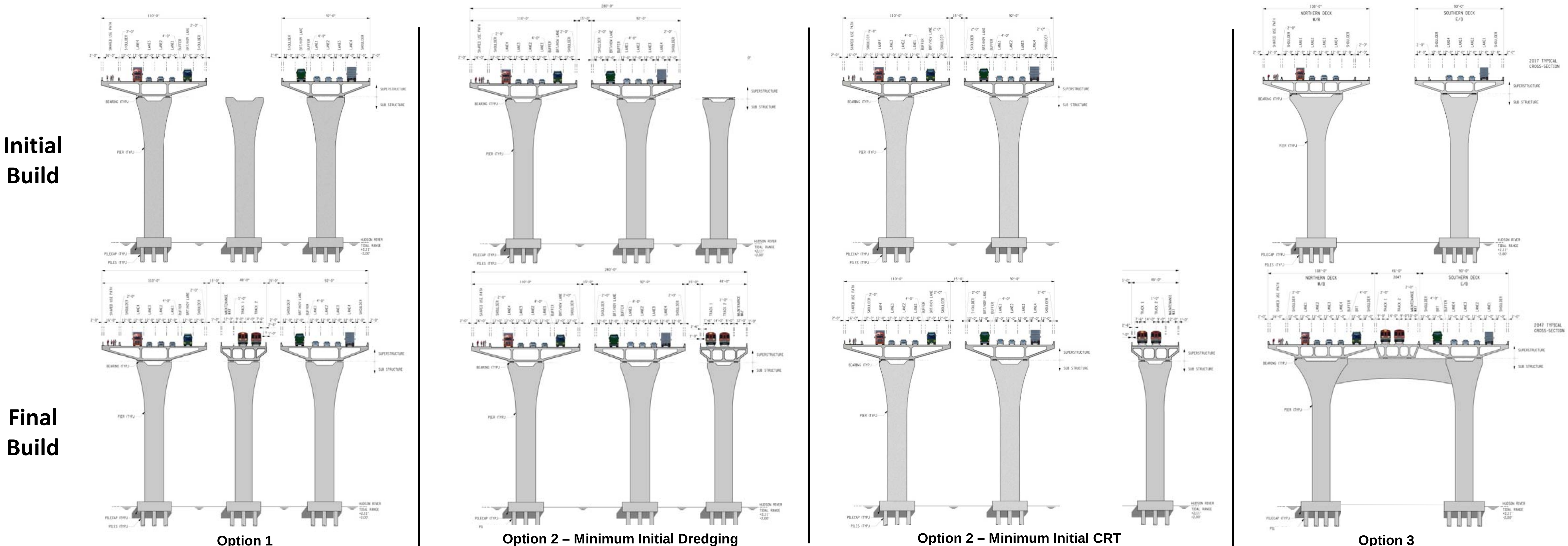


Figure 3.22 - CRT Phasing Potential for Single Level Options

3.4.9 Summary of Engineering Evaluation

The following criteria were identified as differentiators:

- Structural Integrity – with Option 3 having a 11-13% reduction in number of piles and foundation sizes over Options 2 & 3, and Options 1 and 3 having a more efficient Main Span (symmetrical form and fewer towers), than Option 2
- Operations and Risk, as well as Emergency Response – with Option 3 having superior access for emergency response to a major CRT incident by way of direct access from both east and westbound highway shoulders to the continuously adjacent CRT deck. For Options 1 & 2(minimum dredge) access to the CRT deck from the highway shoulders would be intermittent 15-foot long footbridges, and for Option 2 from the eastbound outside shoulder only. For Option 2 (minimum CRT), the footbridges would also be 100 feet long.
- Construction – Option 3 has the smallest dredge volume, followed by Option 1. The dredge volume for Option 2 initially may be smaller, but in both its variations is significantly (39-50%) greater through Final Build than Option 3. The Initial Build construction duration of Option 3 is also 6 months shorter than that of Options 1 and 2.

The following observations and considerations were noted regarding the single-level options.

While the Option 1 and 2 approach structures appear similar, Option 2 would require an extra pair of Main Span towers to independently support the CRT deck. The more efficient piers of Option 3, with two columns and added crosshead beam, results in 33% fewer columns and a significant 11-13% savings in the number of piles and overall foundation size, over Options 1 and 2.

Option 2, with CRT on the side, does provide for crossing the median during major emergency events without interacting with the CRT. In Options 1 and 3, crossing the median would require a temporary suspension of CRT service. Metro-North has indicated that this is not unusual in its operations and is feasible and could be accommodated for major emergencies.

In Option 2, it may prove difficult to provide access to the Main Span CRT suspension cables without interruption of CRT service. Wind may also prove an issue for CRT in Option 2 leading to more frequent suspension of service.

Settlement is predicted to be significant – up to 10 inches over the life of the structure – particularly in the western portions of the crossing, but can be managed through jacking up and re-positioning the superstructure elements.

In the event of a train derailment, the continuous adjoining highway surface of Option 3, provides a degree of failsafe in reducing the probability of a derailed train leaving the bridge. In the event of a train fire, Option 3 with its both of its highways continuously adjacent to the CRT deck, provides the best access for first responders. Option 1, with bridges between both highway decks to the CRT deck in the center, is less desirable, while Option 2, can only provide bridges from the eastbound south roadway.

If construction of the CRT is phased to occur subsequent to construction of the BRT/Highway decks, Option 1 would require a significant portion of the CRT sub-structure (piles, pile caps and columns) to be pre-constructed, resulting in unused columns standing between the two BRT/Highway decks until the CRT deck is finally constructed. With Option 2, CRT construction can be fully phased, however it comes at a significant cost as a significant amount of supplemental dredging (1 mcy) would have to be undertaken. This dredging, which may consisting mostly of newly re-deposited material would likely be classified as contaminated and could be ineligible for deposition at the HARS site. The costs and logistics of upland disposal of this material would be quite significant.

To minimize this dredging, the CRT substructure of Option 2 could be pre-constructed during Initial Build similar to Option 1. CRT foundations and columns would await the construction of the CRT superstructure during Final Build. While subsequent completion of the CRT would use gantry methods to construct the approach super structure, additional dredging would still be needed to construct the CRT Main Span.

Option 3 was designed to be able to phase the construction of its CRT deck. The initial construction would incorporate necessary structural capacity to carry the CRT loads but would not require the placement of any unneeded elements. Adding the CRT would be relatively straightforward, would not require any additional dredging and could be conducted from the already built highway decks. The construction duration of Option 3 is 6 months shorter than the 5.5 years needed for Options 1 and 2.

3.5 Transportation Evaluation

Transportation
Roadway Congestion
Alternative Modes
Mode Split
Transit Ridership
Non-Vehicular Travel
Reserve Capacity
Transportation System Integration

The transportation evaluation criteria are generally systemic in nature and measure effects that are system wide. The RTZB options all convey the same modes and provide the same relative capacity for each of those modes. The supporting elements (shoulders, speeds, etc.) are the same across all options. As a result, Transportation criteria are not anticipated to be a differentiator in the selection of RTZB options

3.5.1 Roadway Congestion

Under the BRT HOV/HOT alternative, roadway capacity is the same across the single-level options for BRT, non-BRT, permitted HOV and candidate HOT vehicles by way of the eight general purpose lanes (four each way), and for BRT, HOV and electing HOT vehicles in the two HOV/HOT lanes (one each way). If the Busway alternative is selected, roadway capacity is still the same across the single-level options; however, for non-BRT vehicles and candidate HOV vehicles, roadway capacity is less than that of the HOV/HOT alternative as, non-BRT vehicles, including HOV and HOT vehicles would not be permitted in the RTZB BRT lanes and would have to remain in the general purpose lanes.

While there is a difference in overall roadway capacity between the HOV/HOT and Busway alternatives, overall roadway capacity for each alternative is the same across the single-level options, thus roadway congestion is not a differentiator.

3.5.2 Alternative modes in mixed traffic

Under the BRT HOV/HOT alternative (available for all single-level options), BRT buses would share the HOV/HOT lane with a limited amount of general purpose traffic with the requisite occupancy, or that have opted into the HOT lane by payment of a toll. The effect of the limited number of non-BRT vehicles upon BRT operations in the HOV/HOT lanes is anticipated to be slight. Busway alternatives would not permit non-BRT vehicles to use the BRT lane on the RTZB.

For travel on the RTZB, alternative modes in mixed traffic is not a differentiator.

3.5.3 Mode Split

Mode split would not be different under any of the three single-level options.

3.5.4 Transit Ridership

All single-level options provide identical capacity and travel times for CRT by way of the two CRT tracks on a fully independent guideway. The HOV/HOT alternative may provide less capacity and potentially slightly longer travel times than the Busway alternative (since BRT vehicles would share the bus lane with HOV and HOT vehicles). Between the two BRT alternatives, however, capacity is the same across the single-level options. Transit ridership would not be different under any of the three single-level options.

3.5.5 Non-vehicular travel

All single-level options provide identical capacity for non-vehicular travel by way of the Shared Use Path. Non-vehicular travel would not be different under any of the three single-level options.

3.5.6 Reserve capacity

All single-level options provide 4 general purpose traffic lanes, a fifth BRT lane, and two 12-foot shoulders in each direction. Conversion of any of these elements to general purpose roadway is possible and would be equally feasible under Options 1-3. Reserve capacity is not a differentiator.

3.5.7 Transportation System Integration

The ability of the transit systems within the I-287 corridor to facilitate transfer between auto, bus and rail modes would be the same for all single-level options. The various single-level RTZB options would be able to provide identical capacity to facilitate mobility within the regional elements of the Interstate and local highway systems. Integration of the Transportation System would not be different under any of the three single-level options.

3.5.8 Summary

All single-level options have identical capacity under the Busway Alternative and under the HOV/HOT Alternative and equal capability to address the project's transportation purposes and needs. Transportation Criteria is not a differentiator.

3.6 Environmental Evaluation

Environmental	
Construction	**Operation**
Displacement Acquisitions	Land Use
Historic Resources	Displacement Acquisitions
Archeological Resources	Historic Resources
Parkland 4(f)	Archeological Resources
River Ecology	Parkland 4(f)
Community Noise	River Ecology
	Avifauna
	Visual

The bridge replacement options have been evaluated using several key environmental criteria. The criteria encompass both the natural and built environment and the evaluation is focused on impacts within a study area bounded on the west by Interchange 10 in South Nyack and on the east by Interchange 9 in Tarrytown.

3.6.1 Land Use

Land use criteria as applied to environmental assessments typically focus on the consistency of proposed projects with local land use policy, as expressed in zoning and other land use policy documents such as master plans, coastal zone management plans, and urban renewal plans. While zoning codes regulate the permitted use, bulk, and other attributes of projects (site layout, design, parking, etc.), state highway projects are not subject to such local ordinances and highway characteristics are not usually addressed in zoning. However, highway projects may have land use consequences, both direct and indirect. For example, land uses (residential, commercial, industrial, etc.) may be displaced, and highways may alter the character of a neighborhood or may induce new development, desired or otherwise. Acquisitions and displacements are addressed separately in Section 3.6.2.

In the context of assessing various bridge options, land use criteria are focused on (1) the project's consistency with local land uses and land use policy and (2) on the potential for transit-oriented development (TOD).

Rockland

In Rockland, the relevant local communities are the villages of South Nyack and Grand View-on-Hudson. Grand View-on-Hudson is a narrow 2.5-mile long strip of Hudson River waterfront; its northern border is South Nyack at the TZB landing. Zoning ordinances in these communities do not address the TZB. Neither community has a master plan. Grand View is zoned exclusively residential and South Nyack is almost exclusively residential. South Nyack has attempted to extend public waterfront access (e.g., the recently developed Gesner Avenue Park at the water's edge). Thus, plans to include a SUP on a new Tappan Zee bridge would appear to be consistent with such policies to facilitate public access to view the river. The bridge SUP would be accessed from local streets in South Nyack. As all options provide SUP, this element is not a differentiator among options.

During construction of all bridge options, the South Broadway bridge connecting areas north and south of the Thruway, would be reconstructed for approximately 10-18 months. The potential alignment may result in additional displacements and acquisitions to properties located along Cornelison Place, Smith Avenue, Elizabeth Place and South Broadway, and would likely alter the land use character of this low-density neighborhood. However, given that all options require the reconstruction of this bridge, this element is not a differentiator among options.

With respect to Transit Oriented Development (TOD) in Rockland, all RTZB options provide equivalent capacity and facility for transit, thus, there is an equivalent potential for TOD for all single-level options.

Land use implications are not a differentiator among the single-level options in Rockland.

Westchester

In Westchester, the relevant local community is the Village of Tarrytown. Tarrytown has a 2007 comprehensive plan, a zoning ordinance, and a Draft Waterfront Revitalization Plan (which still must be approved by New York State). Tarrytown's Comprehensive Plan describes the TZB project status and states that the Village intends to work with officials to mitigate any negative impacts to the village. The plan recommends that Riverwalk remain uninterrupted where it currently is planned to pass beneath the existing bridge. Tarrytown's zoning ordinance does not address the TZB. However, permitted uses in the vicinity of the bridge include a variety of commercial and high density residential uses, resulting in a secondary commercial center, as compared to its traditional downtown near the Tarrytown Station. The village's Draft Waterfront Revitalization Plan emphasizes achieving public access to the waterfront. Construction of a SUP on a replacement bridge would be consistent with this plan and would connect with the already partially constructed Riverwalk project in Tarrytown to provide a continuous esplanade along the Tarrytown waterfront. All options provide for a SUP, so this element is not a differentiator among options.

Land use implications are not a differentiator among the options in Westchester

3.6.2 Acquisitions and Displacements

Bridge options that extend beyond the existing NYSTA ROW are likely to require the acquisition of private or public property. Acquisition that is of a minor character (e.g., a sliver alongside a rear yard) may not require the displacement of the property's occupants. However, when acquisition is of a scale that affects structures or denies access to the property, displacement may be a necessary consequence. There are also situations where use of a property is required but may be only in the form of an easement (e.g., permanent easement for a tunnel below ground); alternatively, such easements may be only temporary for the period of construction (e.g., to gain access to build a retaining wall).

Given the current level of project design, there is of necessity some uncertainty as to the precise level of takings that would occur to develop any particular option. Thus, the number of displacements and acquisitions indicated in Table 3.3 should be considered approximations.

In Rockland, the addition of shoulders, accommodation for CRT and HOV/HOT lanes for all single-level bridge options would result in displacements and, beyond displacements, necessitate additional acquisition of land and temporary or permanent easements. In Westchester, no displacements would occur under the single-level options. With the exception of Option 2 (Minimum CRT), all acquisitions occur during Initial Build. Option 2 (Minimum CRT) results in the greatest overall number of displacements, the greatest acreage acquired, and would affect the most dwelling units, though most of the impacts would occur during Final Build. Option 1 is almost as impactful as Option 2 (Minimum CRT), displacing one less residence. Option 2 (Minimum dredge) and Option 3 result in the least permanent impact to properties located within bridge landing areas.

Acquisitions and displacements are a differentiator among the single-level options.

Initial Build (Final Build) Configuration				
Screening Criteria	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Number of Displacements (Rockland County only)*	13	3 (11)	6	6
Number of Dwelling Units (Rockland County only)*	17	5 (13)	7	7
Acquisitions in Acres in Rockland County	1.32	2.15	0.78	0.74
Acquisitions in Acres in Westchester County	0.31	0.31	0.31	0.31
Initial Build Construction				
Screening Criteria	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Easements in Acres in Rockland County	0.7	4.10	0.66	0.65
Easements in Acres in Westchester County	0.44	0.43	0.43	0.44

* There are no displacements in Westchester County

Table 3.3 – Initial Build and Final Build Displacements and Acquisitions for Single Level Bridge Options

3.6.3 Historic Resources

As noted in Table 3.4, Option 1 would have the most significant direct impacts on historic properties because it may result in potential displacement of three historic architectural resources: Recommended National Resource Eligible (RNRE) 321 South Broadway, 10 Ferris Lane, and River Road Historic District resources. Option 2 may result in potential displacement of RNRE 321 South Broadway and River Road Historic District resources. Option 3 would result in potential displacement of River Road Historic District resources.

Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
ROCKLAND			
RNRE South Nyack Historic District (easement)	RNRE South Nyack Historic District (easement)		
RNRE 78 Smith Avenue (easement)	RNRE 78 Smith Avenue (easement)	RNRE 78 Smith Avenue (easement)	RNRE 78 Smith Avenue (easement)
RNRE 321 South Broadway (potential displacement; temporary easement)	RNRE 321 South Broadway (potential displacement; temporary easement)	RNRE 321 South Broadway (potential displacement; temporary easement)	RNRE 321 South Broadway (easement)
RNRE 10 Ferris Lane (potential displacement; temporary easement)	RNRE 10 Ferris Lane (potential displacement; temporary easement)	RNRE 10 Ferris Lane (easement)	RNRE 10 Ferris Lane (easement)
RNRE River Road Historic District (potential displacement)	RNRE River Road Historic District (potential displacement)	RNRE River Road Historic District (potential displacement)	RNRE River Road Historic District (potential displacement)
WESTCHESTER			
None	None	None	None

Table 3.4 - Direct Impacts to Historic Resources - Single Level Options

The three single-level options would indirectly impact the same historic architectural resources (Table 3.5). These include National Historic landmarks (NRL), National Register Listed (NRL) resources, and RNRE properties and districts. The Visual Resources section (3.6.8) concluded that Option 3 would have the least adverse visual effects because it would be supported on two columns rather than on three columns. In summary, Option 3 would have fewer direct and indirect impacts on historic architectural resources.

ROCKLAND	WESTCHESTER
• RNRE South Nyack Historic District • RNRE 78 Smith Avenue • RNRE 321 South Broadway • RNRE 10 Ferris Lane • RNRE 4 Salisbury Place • RNRE 5 Salisbury Place • NRL Wayside Chapel • RNRE River Road Historic District	• NRL Tarrytown Lighthouse • NRE Tarrytown Railroad Station • RNRE Tappan Landing Historic District • RNRE Irving Historic District • RNRE Hudson River Railroad • NHL Lyndhurst • NHL Sunnyside • NRE County Waterfront Park • RNRE South End Historic District • RNRE Matthiessen Park Historic Buildings • NRE Irvington Historic District

Table 3.5 - Historic Resources with Indirect Visual Impacts

Historic resources are a differentiator among the single-level options.

3.6.4 Archaeological Resources

In Rockland County, the three options would have direct impacts to previously identified and potential archaeological resources. All options would impact previously identified New York State Museum (NYSM) Site 6402. Under all options, the areas of archaeological sensitivity that may be directly impacted include Elizabeth Place Park, the front and side yards of two structures on Elizabeth Place and Broadway and the yard areas of several structures along the southern I-287 ROW between Broadway and Bight Lane (off River Road). Option 2 (Minimum dredge) would have the fewest direct impacts to potential archaeological resources, while Option 2 (Minimum CRT) would have the most direct impacts, followed by Options 1 and 3.

In Westchester County, there are no previously identified sites that would be directly impacted by any of the single-level options. The area inboard of the Metro-North ROW is a previously undisturbed area, which is sensitive for prehistoric archaeological remains. All options would impact this area.

Within the Hudson River, the various Options would directly impact the bed of the river, and therefore, any potential archaeological resources that may be present. Research on the archaeological potential of the Hudson River bottom, is on-going as part of the Section 106 (36 CFR 800) compliance study for this project.

Archeological resources are a differentiator among the single-level options.

3.6.5 Parklands / 4f

Potential effects to parklands are an important consideration that typically require an analysis under Section 4(f) of the Transportation Act. This analysis would require, among other elements, an assessment of avoidance alternatives. A determination that no other feasible and prudent alternative exists is required.

There is one affected park in the area of the TZB landings (Elizabeth Place Park) and a small (unnamed) seating area across from this park on South Broadway, in South Nyack, Rockland County. These small neighborhood resources (approximately one acre in total) would be affected by all options by requiring acquisition of a strip of their northern boundary with the Thruway.

The construction of the minimum CRT version of Option 2, however, would significantly impact both park resources, essentially eliminating them and their associated tree buffer and requiring their full reconstruction. In conclusion, Parkland/4f issues are a differentiator adverse to Option 2 minimum CRT.

3.6.6 River Ecology

The comparison of potential impacts provided herein is a relative comparison, not a conclusion with respect to absolute impacts. Thus, when it is stated that the impacts of one option are greater than those of another, a judgment is not being made as to whether or not either impact level is, or is not, significant. That level of evaluation will be presented in the project's *DEIS* after considerable analysis and consultation with regulatory agencies.

Options 1 and 2 differ only in the location of the CRT structure, and subsequently do not differ in any of the quantitative Hudson River Ecosystems and Water Resources criteria considered. Option 3 presents a slightly narrower alternative structural single-level bridge design with different impacts when compared to Options 1 and 2. In-River Impacts are presented in Table 3.6. In this table Initial Build values are presented without parentheses. Where subsequent Final Build impacts occur, these additional values are presented within parentheses.

Shading of River

Shading of the river is based upon RTZB deck area over the river and would be the same for cable-stayed and arched Main Span options. Option 3 would result in marginally smaller shaded area when compared to Options 1 and 2. However, the 1.6% difference is not significant. Shading of River is not considered a differentiator

Stormwater Quality

The impervious area calculated for storm water quality is the deck area from abutment to abutment and is slightly larger than the area calculated for river shading. Again, Option 3 has marginally smaller impervious surface than Options 1 and 2, however, the 1.6% reduction is not significant. Stormwater quality is not considered a differentiator

Permanent Loss of Habitat

Net river bottom habitat loss (area covered by pile caps, less approximately 5 acres of reclaimed habitat after removal of existing TZB) of Option 3 is less (essentially zero acres) than that of Options 1 and 2 (2.0 to 2.2 acres). This small area of permanent habitat loss, relative to the extensive river bottom habitat of the Tappan Zee estuary, is not a considered a differentiator.

Volume of Water Displaced

Due to the smaller number of foundations, the pile caps of Option 3 displaces less water than the other Options. There is a 14% increase in water column displaced by Options 1 and 2 when compared to Option 3. Relative to the volume of water available in the Tappan Zee estuary, the difference in the volume of water displaced is not considered a differentiator.

Wetlands

Impacts to incidental shoreline wetlands occur entirely at the Rockland bridge landing and comprise less than half an acre. Option 1 has slightly more effect on these marginal wetlands while Option 3 is virtually equivalent to Option 2. Wetlands are not a differentiator.

In-river Habitat

The addition to the river of hard substrate provided by the replacement bridge pile caps is considered a positive feature of the new bridge. Options 1 and 2 provide a larger area of underwater habitat than Option 3. In-river Habitat is considered a minor differentiator.

Underwater Acoustic Impacts

The more structurally economical foundation system of Option 3, relative to Options 1 and 2, reduces the total number of foundation piles required by 11-13% (Table 3.1) resulting in less acoustic impacts during pile driving to aquatic resources. Underwater acoustic impacts are considered a differentiator in favor of Option 3.

Suspended Sediment

Suspended sediment loading is based upon expectation of losses (approximately 1% of volume) during dredging. The volume of dredging required (Table 3.2) results in an anticipated sediment loading for Option 1 of 17.7 thousand cubic yards (tcy), and for Option 3 is 16.5 tcy. Option 2 under the Minimum CRT version would produce 15.8 tcy of suspended sediment during Initial Build, and an additional 0.90 tcy during Final Build, a total of 24.8 tcy. The Option 2 minimum dredge version is only slightly better with a larger up front Initial Build dredge yielding 17.7 tcy of suspended sediment, then 5.2 tcy produced during Final Build to re-open the access channel, for a total of 23.9 tcy.

The difference in the dredge volumes relative to Option 2 is significant, with a reduction of 26% for Option 1 and 31% for Option 3. The 7% reduction in dredge volume for Option 3 over Option 1 reflects the closer transverse spacing of its bridge columns. Suspended sediment loading is a significant differentiator adverse to Option 2.

Temporary Loss of Habitat

Differences in the temporary loss of river bottom habitat between bridge options are influenced most heavily by the area of the dredge prism. In-river construction access and mooring facilities are expected to be similar regardless of the Bridge Option selected. Dredging area, however, is reflective of the type of barge movements and the construction methods that are necessary to the construct a specific bridge type. Options 1 and 2 have a larger dredge area than Option 3. Moreover, if the construction of the CRT is phased, Option 2 has approximately half again as much disturbance of river bottom compared to its full build construction program, and compared to the other Options. Accordingly, there is a modest preference for Option 3 under full build of highway, BRT and CRT, and a decided bias against Option 2 if construction of CRT is phased. Temporary loss of habitat is considered a differentiator against adoption of Option 2.

Duration

Construction duration is closely tied to the number of individual elements that need to be constructed. It is also a measure of the cumulative daily impact of construction operations including noise, dust, traffic and other nuisances. Option 3, which has significantly fewer bridge piers compared to Options 1 and 2, results in a shorter full build construction schedule by 6 months. Duration is a significant differentiator in favor of Option 3.

Initial Build (Final Build) Configuration				
Screening Criteria	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Shading of River (acres)	70.5 (16.7)	70.4 (16.8)	70.4 (16.8)	69.2 (16.1)
Impervious Surface / Stormwater Quality (acres)	75.1 (17.8)	75.0 (17.8)	75.0 (17.8)	73.8 (17.1)
Permanent Loss of Habitat (acres)	7.0	4.7 (2.4)	7.2	4.9
Volume of Water Displaced (acre-feet)	53.7	36.2 (18.7)	55.0	37.5
Wetlands (acres)	0.43	0.31	0.31	0.34
In-river Habitat (vertical surface area – acres)	6.4	4.3 (2.3)	6.6	4.6
Initial Build (Final Build) Construction				
Screening Criteria	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Underwater Acoustic Impacts (no. of in-river piles)	2216	1494 (772)	2266	1968
Suspended Sediments (volume in thousand cubic yards)	17.7	15.8 (9.0)	17.7 (5.2)	16.5
Temporary Loss of habitat (acres)	166	166 (90)	166 (70)	155
Duration (years)	5.5 (2.2)	5.5 (3.4)	5.5 (2.4)	5.0 (3.0)

Table 3.6 - Initial Build and (Final Build) Ecological Comparison of Single Level Bridge Options

Summary of In-River Impacts

When considering the long term operating impacts of the single-level Options, Option 3 presents a number of modest advantages over Options 1 and 2 with regard to shading, impervious surfaces, loss of habitat and reduced water column displacement. With regards to potential long term in-river effects, there is no clear preference among the bridge options. When considering the construction effects for the single-level bridge options, Option 3 would be preferable since it requires 11-13% fewer piles, 7-31% less dredging with reduced suspended sediment loading, and a 9% shorter Initial Build construction duration.

With respect to the phasing of construction, the subsequent addition of the CRT deck results in a similar level of Initial and Final Build shading and stormwater quality impacts across the options. The permanent loss of habitat, volume of water displaced and in-river habitat effects of Option 2 (minimum CRT) during Initial Build are similar to the Full Build effects of Option 3, however the Final Build effects of these Option 2 (minimum CRT) issues result in total effects similar to Option 1 and Option 2 (minimum dredge).

3.6.7 Avifauna

Two concepts for the RTZB Main Span are under consideration – cable stay or arch. Based on the current level of conceptual design information, it is expected that a cable-stayed Main Span would have the same approximate proportions (tower height and cable array width) for the three single-level Options. It can also be expected that the width and breadth of an arch Main Span would be similar for the single-level Options. Impacts to avifauna are not considered a differentiator in this analysis.

3.6.8 Visual

Two key criteria in assessing visual effects are: the degree of anticipated change to the visual context (or resource); and the anticipated reaction by viewers to the proposed changes. In this case, the TZB context is the most scenic resource on the I-287 Corridor. Moreover, the Hudson River, in this reach of the Tappan Zee, is an especially valued visual resource because of its wide expanse of open water and sky (the river is 2.75 miles wide at the bridge), permitting broad panoramas across the river and extended vistas north and south of the bridge, The Tappan Zee reach is framed to the west by the dramatic Palisades escarpment (with cliffs up to 600 feet high), and more generally by the wooded ridges of both Westchester and Rockland Counties. It is a visual context enjoyed by tens of thousands of residents who view the river, as well as the drivers and passengers of the more than 130,000 daily motorists on the TZB, a variety of boaters, and visitors to the many cultural and recreational resources along the river, such as Lyndhurst, or the Scenic Hudson Park in Irvington.

Photo-simulations of RTZB options have been created and can be found in Appendix B. The visual characteristics of the replacement bridge differ from the existing bridge in several ways:

- all the options are wider than the existing bridge,
- the profile of the bridge for much of its western causeway will be raised (to provide appropriate grades for CRT), and
- the depth of the deck structure will be greater.

These changes will generate a greater intrusion to the visual context (Table 3.7). The change in profile will potentially affect the sight lines of the Palisades from specific properties. On the other hand, the existing TZB has 200 columns in the river, while the single-level options reduce this number to 88, thereby providing greater transparency beneath the bridge for both nearby residents and boaters. Moreover, the distances involved and available sight-lines are likely to limit the impact of the visual changes to those viewers close to the bridge landings. Because the replacement bridge would be to the north of the existing bridge, affected viewers are more likely to be located to the north of the bridge. These affected viewers would be likely to have strongly negative reactions to a taller, wider bridge located closer to them, intruding upon or foreclosing existing views of the river.

All three single-level options provide the same profile, so change in profile is not a differentiator. Similarly, all provide a series of 61 column/piers. Option 3, however, provides this series of columns as pairs, whereas Options 1 and 2 are a series of three columns, permitting less transparency, especially when viewed obliquely. Moreover, Option 3 places the deck for CRT, which is deeper than the roadway decks in the center of the roadways, whereas Option 2 would place it to the south where its bulk would be more visible. These differences place Option 3 as having the least adverse visual effects.

Visual effects can be considered a differentiator in the single-level options

Screening Criteria	Option 1	Option 2	Option 3
Change in Visual Impact	• 61 piers of 3 columns • higher bridge profile • deeper deck structure	• 61 piers of 3 columns • higher bridge profile • deeper deck structure	• 61 piers of 2 columns • higher bridge profile • deeper deck structure.
Reaction to Visual Impact	• Adverse visual reaction from viewers of existing landings to all options • Improved views for some, e.g., boaters and some close-in resident viewers • Deeper CRT deck in center less intrusive	• Adverse visual reaction from viewers of existing landings to all options • Improved views for some, e.g., boaters and some close-in resident viewers • Deeper CRT deck on south side more intrusive	• Adverse visual reaction from viewers of existing landings to all options. • Improved views for some, e.g., boaters and some close-in resident viewers. • Deeper CRT deck in center less intrusive. • Greater visual transparency with 2-column series than Options 1 and 2.

Table 3.7 - Single Level Visual Comparison of Bridge Options

3.6.9 Community Noise

The single-level bridge options being compared are not expected to significantly impact either traffic flows or transit service plans. Thus traffic flows and transit movements are not considered differentiators in terms of potential to impact community noise levels.

Bridge construction activity near the landings, with its potential for causing community noise impacts, has been identified as the differentiating element for making comparisons among the options. Since pile driving is likely to be a major noise source during bridge construction, the number of piles to be driven for a particular option has been selected as the specific basis for comparing options (Table 3.8). With regard to the single-level options, Option 3 requires approximately 11-13% less pile driving than Options 1 and 2. The overall Initial Build construction duration of Option 3 is also 6 months less than the other single-level options. Thus, among the single-level options, Options 3 has a relatively lower potential to impact community noise levels. Given the scope of pile driving required and the potential for a 6 months reduction in overall construction activity and associated noise, community noise is considered a differentiator adverse to Options 1 & 2.

With the exception of Option 2 under the minimum CRT version, the alignments of the single-level options at the landings are sufficiently similar that impacts to community noise levels due to differences in alignment are not considered differentiators.

Under minimum CRT version of Option 2, construction of CRT would, of necessity, occur in proximity to residences situated south of I-287 and between the river and Interchange 10. Community nose levels could be notably increased in comparison to the other single-level options due to the south CRT alignment. Community noise is a further adverse differentiator to Option 2 under the minimum CRT version.

Screening Criteria	Option 1	Option 2 minimum CRT	Option 2 minimum dredge	Option 3
Community Noise Impacts (Total no. of piles)	2300	1550 (800)	2350	2043

Table 3.8 - Initial Build and (Final Build) Community Noise Comparison of Single Level Options

3.6.10 Summary of Environmental Criteria

With regard to single-level options, Option 3 has least impact to the resources evaluated herein. Option 1 has significant impacts to properties, including twice as many displacements as the other options, a number of which are historic resources. Option 1 also has greater in-river and visual impacts than Option 3. Option 2 has significant impacts to in-river resources as well as greater visual impacts to surrounding communities. The minimum CRT version of Option 2 also significant acquisitions and displacements comparable to Option 1. The minimum dredge version of Option 2 has similar property impacts as Option 3 (6 displacements). The smaller footprint in the river and more compact structural form of Option 3 give it the least in-river and visual impacts (Table 3.9).

Phasing CRT construction would be expected to have additional environmental impacts under Option 2, as it is the only single-level option to require significant additional in-river work including a second round of dredging and associated pile driving to complete the CRT.

Single Level Options				
Screening Criteria	Option 1	Option 2 Minimum CRT	Option 2 Minimum Dredge	Option 3
Land Use and Transit Oriented Development	ND	ND	ND	ND
Displacements and Acquisitions	X	X	-	-
Historic Resources	X	X	-	-
Archaeological Resources	ND	ND	ND	ND
Parkland/4f	-	X	-	-
Hudson River Ecosystems and Water Resources		X	X	-
Avifauna	ND	ND	ND	ND
Visual	X	X	X	-
Community Noise	-	X	-	-

ND – Not a differentiator X – Significant adverse differentiator

Table 3.9 - Comparison of Environmental Criteria for the Single Level Options

3.7 Cost Evaluations

3.7.1 Capital Cost with Standard CRT Loading

Cost
Capital Cost (cable stayed bridge)
Operating and Maintenance Cost
Life Cycle Costs

This Sub-Section presents details of the Capital Cost for the Initial and Final Build of the single-level options. Operating and Maintenance Costs and Life Cycle Costs were not evaluated in this report. The geographical limits of the work included in the cost estimate are the western limit of Interchange 10 in Rockland County and the eastern limit of Interchange 9 in Westchester County. The estimate includes all construction works for the Replacement TZB and the landings.

3.7.2 Methodology

Details of the estimating methodology used are as follows:

1. Determine the individual structural members of the bridge. These members for the approach structure are foundation piles, pile caps, columns and superstructures. Towers and stay cables are the additional members considered for the Main Span.
2. Determine the components of each member. E.g., for piles these components are steel shell, poured concrete and rebar cage.
3. Determine the size and quantity for each component by the process of structural design and detailing to 15% design level
4. Determine a unit cost for each structural member.
5. Determine the cost for each component from quantity and unit rates.
6. Mark-up for escalation to 2012 dollars.
7. Mark-up for contractors general conditions, insurance, overhead and profit.
8. Mark-up for soft costs such as design, permitting and agency staff.
9. Mark-up for contingency

Unit Costs

Unit costs are based on the estimator's database. They are benchmarked against historical data collected from comparable projects recently built across the US. These unit costs are adjusted for the TZB project location. Unit costs remain the same among options for comparison purposes.

Key Assumptions

- Cost estimates are based on the drawings included in Appendix A
- The cost of the Main Span structure included in this estimate is based on the total surface area of the deck and unit cost
- Main Spans are assume to be of cable stayed type only for the purposes of this estimate
- Maintenance train loading, described in section 2.2, has been adopted
- Construction cost escalation at 4.5% per year has been included to develop costs for the year 2012. Escalation is factored on the total cost
- General contractor's mobilization, overhead, profit, bonding and insurance are estimated at 32%
- Soft cost and contingency are estimated at 30%

Key Exclusions (as they are the same for all single-level options)

- Existing bridge demolition
- Ship collision protection
- Roadway features like lighting, signage etc.
- Track work, signaling, third rail
- Maintenance and operation cost

3.7.3 Single Level Capital Costs

Table 3.10 summarizes the capital costs for the single-level bridge options. For each option, the table identifies total Initial Build costs and allocates the CRT Accommodation share relative to a nominal two-structure Highway/BRT crossing. Though mid-point of Initial Build construction is estimated to be 2015, Initial Build costs are developed in 2012 dollars for consistency with previous cost estimates. Final Build costs for the CRT are also identified and are in 2027 dollars, assuming the midpoint of CRT completion is 12 years following the midpoint of the Initial Build.

Overall, the total Initial Build costs for the single-level options range from $5.99 to $6.67 billion in 2012 dollars. Initial Build costs are lowest for Option 2, assuming minimum initial CRT construction.

The Initial Build costs of Option 3, the next most expensive option, are 14% higher than the Initial Build costs of Option 2. Though these structures look similar (two Highway/BRT decks), Option 3 contains the additional piles and column strengthening needed to support the CRT.

Total cost represents the sum of expenditures to construct the Initial Build elements (in 2012 dollars) and Final Build elements (in 2027 dollars). Total costs range from $8.385 and $8.390 billion for Options 1 and 3, to $10.14 billion for Option 2 with minimal initial CRT construction.

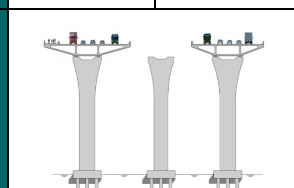
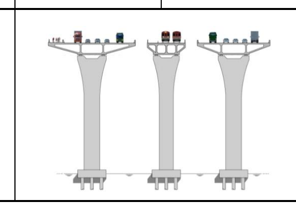
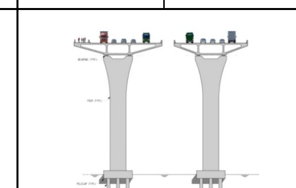
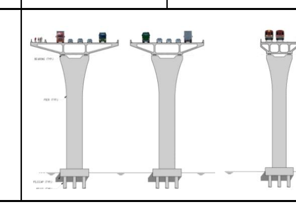
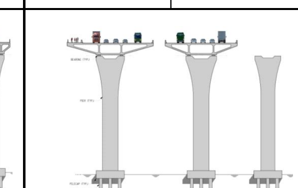
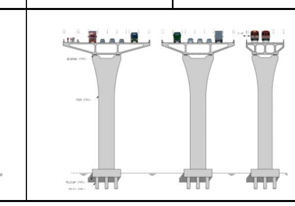
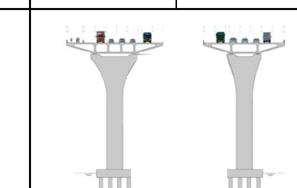
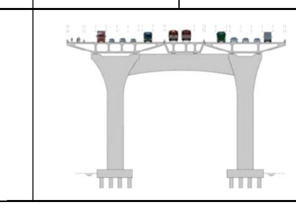
Cost Item	Option 1				Option 2 - 1.2% Highway Grade Minimum Initial CRT Construction				Option 2 - 1.2% Highway Grade Minimum Future Dredging				Option 3			
	Initial Build (2012 $)		CRT (2027 $)	Total	Initial Build (2012 $)		CRT (2027 $)	Total	Initial Build (2012 $)		CRT (2027 $)	Total	Initial Build (2012 $)		CRT (2027 $)	Total
	Total Initial Build	CRT Accomodation			Total Initial Build	CRT Accomodation			Total Initial Build	CRT Accomodation			Total Initial Build	CRT Accomodation		
Approach Structure Cost	$1,805	$246	$593	$2,398	$1,559	$0	$1,069	$2,628	$1,785	$226	$633	$2,417	$1,778	$219	$626	$2,404
Main Span Cost	$699	$0	$175	$874	$699	$0	$453	$1,152	$769	$70	$453	$1,222	$699	$0	$175	$874
Landing Cost (Rockland)	$208	$112	$66	$274	$221	$125	$304	$525	$221	$125	$304	$525	$208	$112	$66	$274
Landing Cost (Westchester)	$148	$18	$0	$148	$148	$18	$0	$148	$148	$18	$0	$148	$148	$18	$0	$148
Dredging & Armoring Cost	$65	$7	$0	$65	$58	$0	$33	$91	$65	$7	$19	$84	$61	$3	$0	$61
Sub Total - Base Cost	**$2,925**	**$383**	**$833**	**$3,759**	**$2,686**	**$143**	**$1,859**	**$4,544**	**$2,988**	**$445**	**$1,408**	**$4,396**	**$2,894**	**$352**	**$867**	**$3,761**
Contingency (30%)	$878	$115	$250	$1,128	$806	$43	$558	$1,363	$896	$134	$422	$1,319	$868	$106	$260	$1,128
General Conditions, Insurance, Overlead and Profit (32%)	$1,217	$159	$347	$1,564	$1,117	$59	$773	$1,890	$1,243	$185	$586	$1,829	$1,204	$146	$361	$1,565
Soft Costs (30%)	$1,506	$197	$429	$1,935	$1,383	$74	$957	$2,339	$1,538	$229	$725	$2,263	$1,490	$181	$446	$1,936
Total Cost	**$6,525**	**$853**	**$1,859**	**$8,385**	**$5,991**	**$319**	**$4,147**	**$10,138**	**$6,665**	**$993**	**$3,142**	**$9,807**	**$6,457**	**$785**	**$1,934**	**$8,390**
Bridge Cross Section																
Notes: 1. Costs are in $millions 2. Landing costs per elements depicted in plans (all options). 3. Rockland CRT Portal constructed during Initial Build	1. No Dredging required for future CRT structure construction.				1. Dredging required for future CRT structure construction.				1. Columns for CRT structure constructed during Initial Build in dredge zone only. 2. Future dredging required to provide shore access to construct CRT Main Span and remaining CRT columns.				1. No future dredging required			

Table 3.10 - Capital Costs for Single Level Bridge Options

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4 Dual Level Options

4.1 Introduction

This chapter describes the three possible options identified in the BODR to replace the TZB with a dual-level structure. This chapter begins with a description how the dual-level options place unique requirements on the configuration of the common elements of the Rockland and Westchester landings. It then describes the three options identified in the BODR to replace the TZB with a dual-level structure.

See Appendix A for detailed drawings of the three Dual Level Options. Additionally, visualizations were created of the dual level options from a variety of locations on both sides of the Hudson River. The visualizations were created to allow the comparison of the configurations with regards to the number of piers and the bridge height and width and therefore, Options 5 and 6 are represented in the visualizations of Option 5. Visualizations can be found in Appendix B.

4.2 Dual Level Landing Considerations

Rockland Landing

Similar to the single-level options, the elevation of the RTZB at its abutment in Rockland is result of the elevation of River Road and its requisite clearance, and the structural depth of the RTZB decks. In developing the dual-level options, the CRT elevation was held at approximately elevation 47 feet, similar to that of the single-level options. The highway/BRT (HOV/HOT) deck for the three dual-level options is located 30 feet above the CRT deck. This places the highway/BRT deck at approximately elevation 77 feet at the abutment. The higher elevation of the highway/BRT deck results in the transition between the (-1.95%) descending upland highway grade and the ascending (1.10%) RTZB grade occurring significantly further inland (approximately 1,300 feet from the abutment, in the vicinity of South Broadway Bridge) than for the single-level options.

With CRT below the Highway/BRT (HOV/HOT) decks, significantly less ROW is required for the dual-level options than for the single-level options. Along the southern boundary, replacement of the South Broadway bridge, requires one acquisition. For Option 5 an additional acquisition is required along the southern boundary. For Option 6, provision along the northern I-287 boundary for the maintenance accessway to the NYSTA Dockside facility with the SUP located above, required the acquisition and displacement of a property on the south side of Smith Ave.

With CRT located below the highway/BRT decks, all CRT elements will be underground after reaching the abutment and transition directly to the start of tunnel without an extended portal. This will require the preconstruction of the start of tunnel structure under the upland highway/BRT lanes. It is anticipated that this start of tunnel structure would extend 3200 feet from the abutment to the vicinity of the existing South Franklin Bridge.

Westchester Landing

Like the Rockland landing, the single-level highway/BRT (HOV/HOT) lanes and CRT descend from the Main Span at a common grade one above the other. Similar to the single-level options, for Options 4 and 5, the HOV/HOT lanes on the RTZB split to continue into the landing as well as to form a Y-shaped two-way BRT Bridge Station Connector (BSC) ramp between the highway lanes and above the descending CRT. Approximately 800 feet from the abutment, the highway lanes split from the BSC to rise above the BSC which curves north under the westbound lanes into the proposed BRT station. For Option 6, the BRT transitions from under the highway lanes to form the BSC and cross over the descending CRT tunnel.

4.3 Option Description

4.3.1 Option 4 – Two Structures - CRT Center Stacked

Option 4 is a unique form (Figure 4.1). It is in some ways similar to Option 3. Like Option 3, the structural system is in the form of a bent with two columns and a crosshead beam. Unlike Option 3, however, the position of the crosshead beam is lower so instead of forming a classic bent, it is more of an H-frame arrangement. Like the single-level options, the highway decks sit atop the columns and the CRT rests atop of the crosshead beam. Unlike Option 3, however, the CRT is 30 feet lower than the highway decks over the entire length of the crossing. Also unlike Option 3, the highway decks do not run adjacent to the CRT deck, but rather come together and close the gap between themselves above the CRT deck. This results in a narrower bridge width (204 feet) than the single-level options. It also results in a higher bridge, both in terms of the depth of the section (approximately 45feet) and its height over the shipping channel (approximately 197 feet).

Replacement Bridge

Option 4 preserves a constant cross section over the length of its approaches. The position of the crosshead beam and CRT relative to the highway decks is constant. Upon reaching the back spans of the Main Span, the cross section transitions from three independent decks supported on an H-frame to a single composite deck that integrates the CRT deck with the two highway decks (Figure 4.2). Given its size, it is anticipated that this composite deck would be fabricated in steel. This single large Main Span deck is necessary as it is not possible for conventional cable stays or hangers to reach and support the CRT deck stacked below the highway decks.

Rockland Landing

At the Rockland landing, passing over River Road, the stacked position of CRT under the highway decks means that the highway decks will be significantly more elevated and further inland at landfall than the single-level options. The highway decks, in fact, reach the same elevation as the existing Thruway at approximately South Broadway Bridge. The highway, however, transitions quickly from structure to abutment on reaching the shore. The CRT likewise quickly enters into a tunnel within the abutment. Like the other options, the CRT continues to descend before beginning to rise again. Above, the highway lanes continue around the reconstructed pier of South Broadway Bridge. If the HOV/HOT form of BRT is adopted, the BRT continues directly in HOV/HOT lanes. If, instead, the Busway form of BRT is adopted, the highway lanes separate slightly to enable the BRT busway lanes to separate from the general purpose lanes. These BRT lanes come together in the center while new shoulders are developed on the inside of the highway general purpose lanes. Once the BRT lanes have come together, they can begin to descend to follow atop of the CRT tunnel envelope. Once adequate clearance is developed, the BRT lanes can transition from the center to the south side of the Thruway to form the busway.

Westchester Landing

In its approach to the Westchester Landing, the cross section transitions from the composite Main Span deck back to the H-frame stacked deck arrangement. Together, both the CRT and highway decks descend towards the escarpment. As the structure approaches the shoreline, two things occur. The highway decks increase in height relative to the CRT deck and begin to curve up, and the two highway decks begin to separate in order to provide for the Bridge Station Connector (BSC) ramps in the center between the highway decks. At this point, the configuration begins to resemble Option 3.at the same location and continues to follow this form into and through the landing.

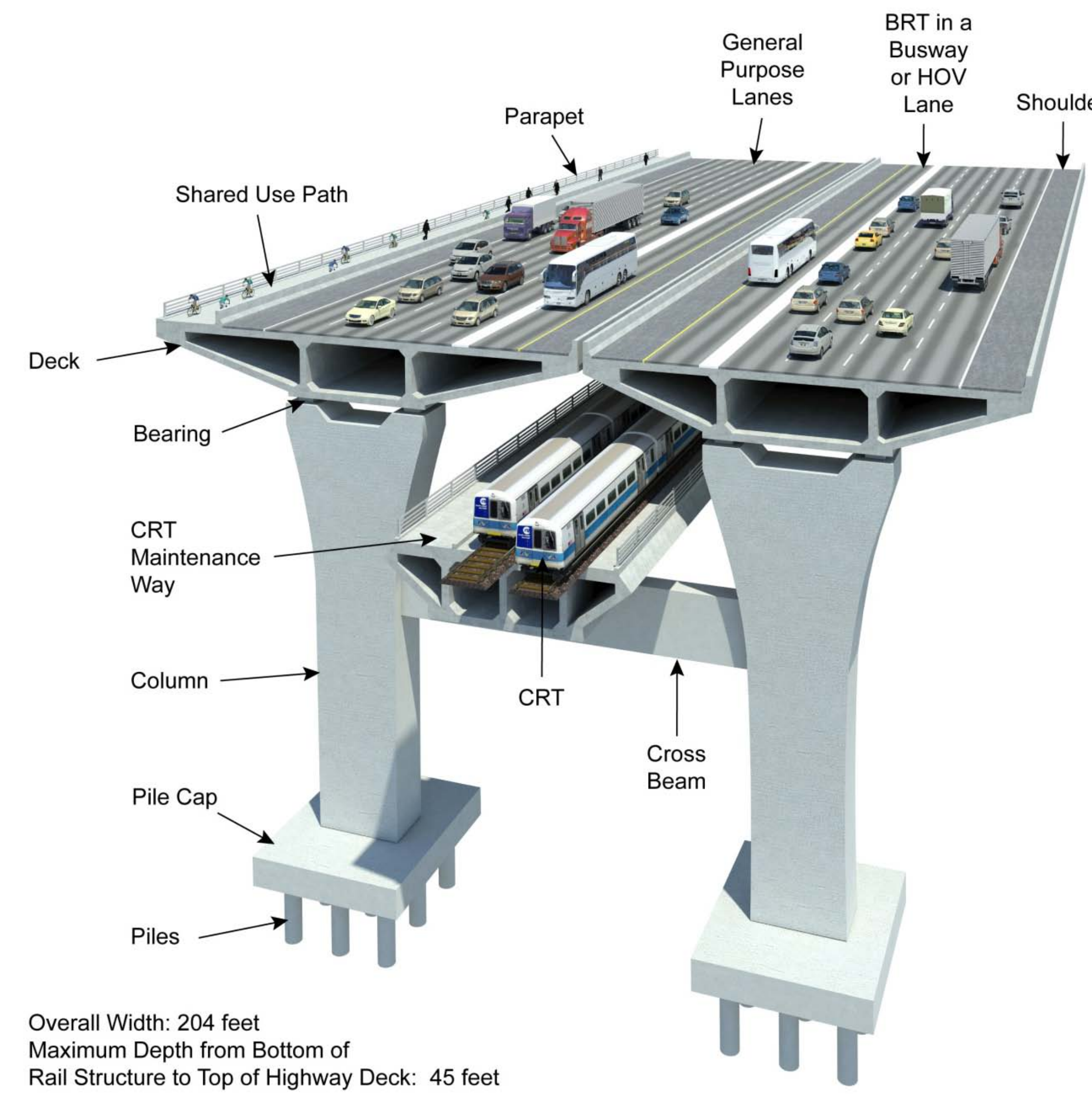
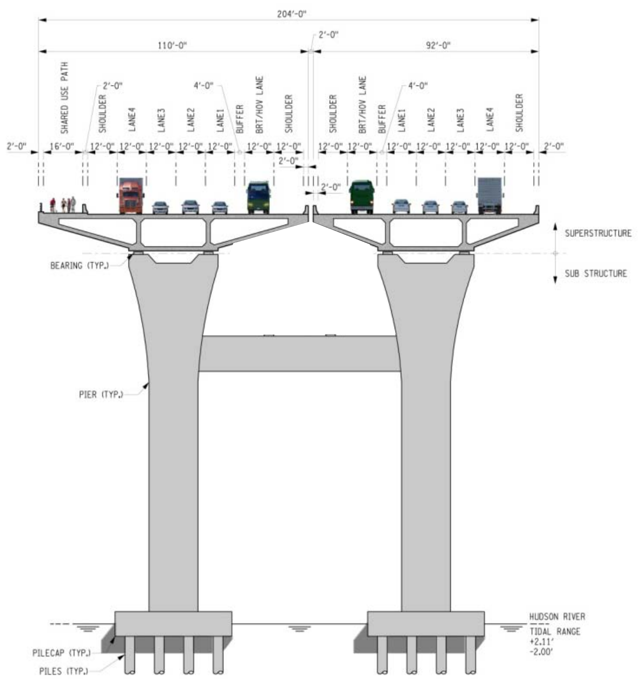
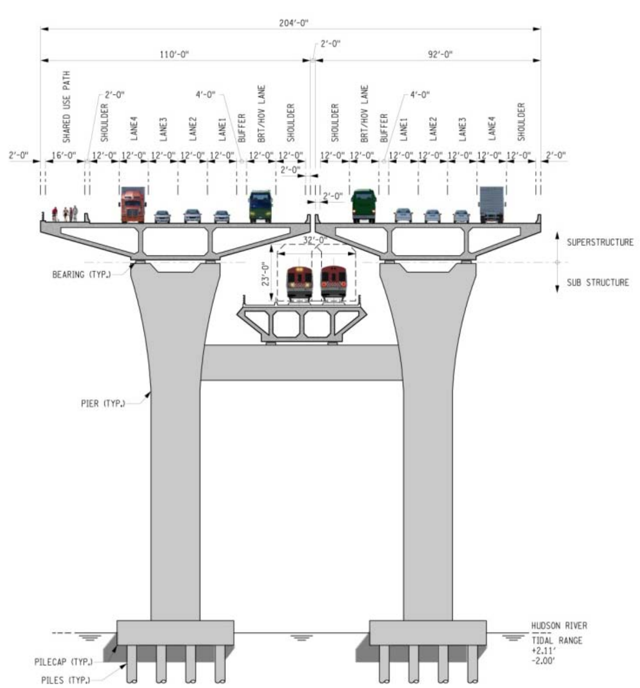


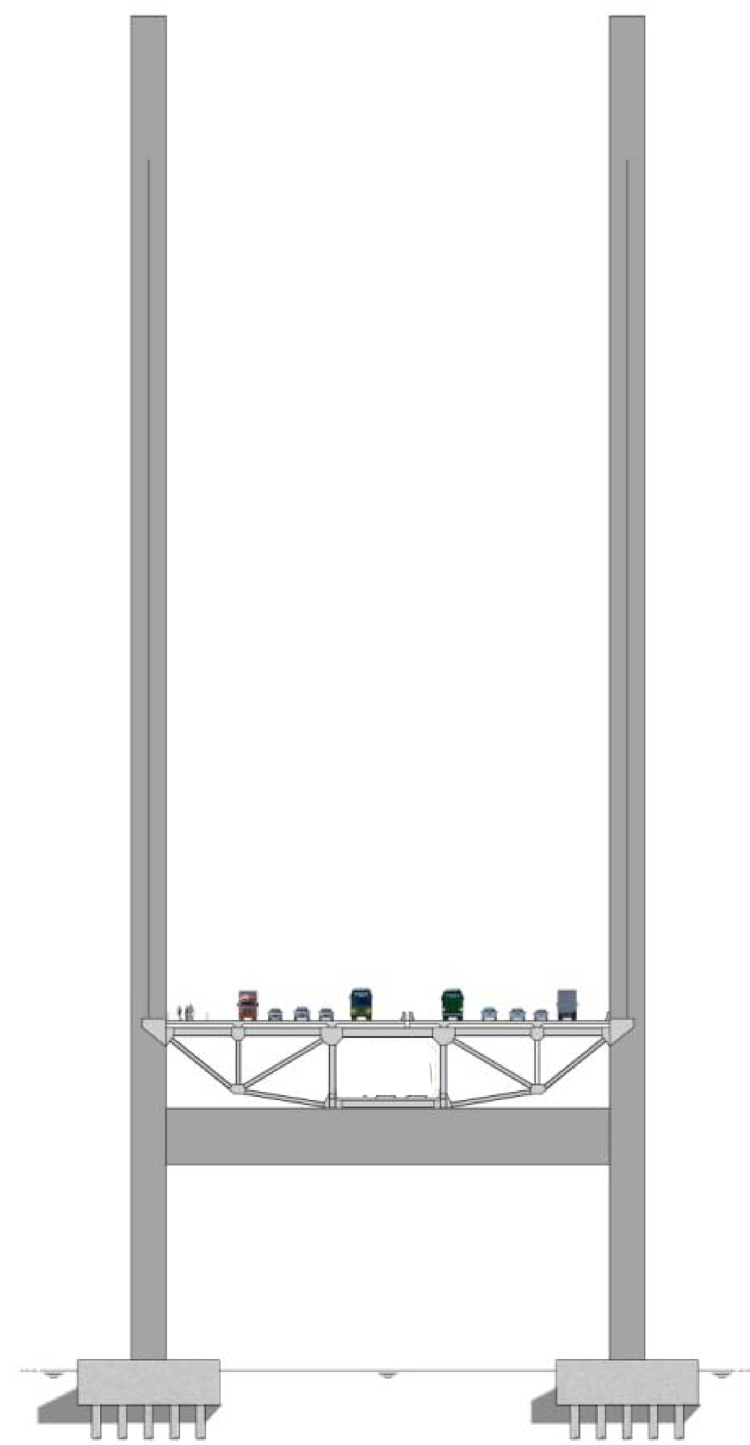
Figure 4.1 - Option 4 – Dual-Level CRT Center Stacked One Structure



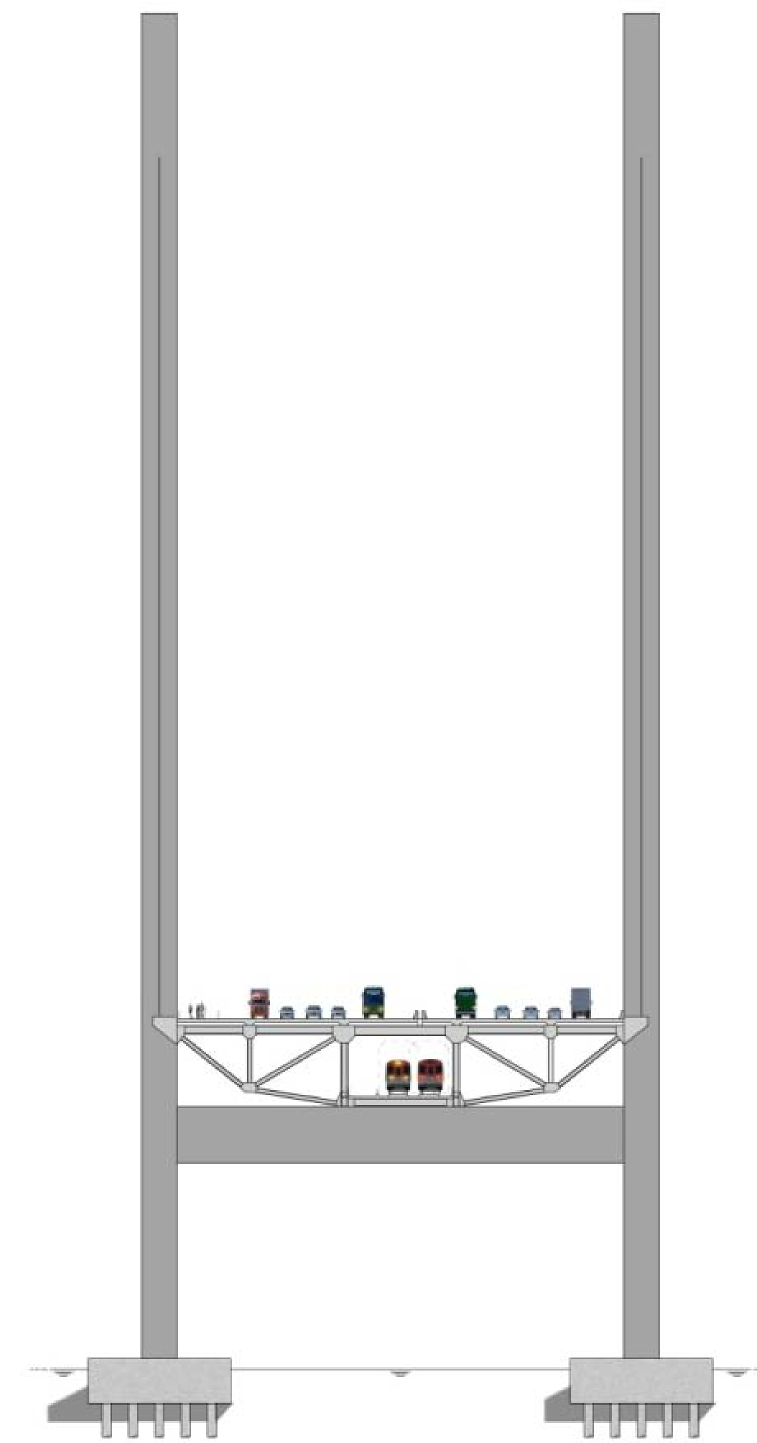
CRT Phasing Potential at Approach Span



CRT added in Final Build



Initial Build Configuration assuming CRT to be implemented at a later date



CRT added in Final Build

Approach Span

Main Span

Figure 4.2 - Option 4 Configurations

Full Build Cable Stayed Option at Main Span

Full Build Arch Option at Main Span

Figure 4.3 - Option 4 - Main Span Options

Construction Sequence

With the CRT brought underneath, the dual-level options are appreciably narrower than the single-level options (Figure 4.2). As a result, their footprint through the landings is smaller. It is still anticipated that the ends of the south spans will overlap the existing TZB, so all traffic will still have to be carried by the north highway deck. It is also still anticipated that the westbound roadway will have to be relocated to the north in Westchester, and the eastbound roadway located to the south in Rockland. The overall extents of those relocations, however will be reduced for the narrower dual-level options.

The H-frame form of the substructure poses a number of problems for the construction. In the landing areas where the RTZB overlaps the TZB, it would be possible to initially build only half of the H-frame. The north highway deck would have to be completely supported on the northern line of columns. Once traffic was transferred from the TZB to this north deck, the interfering portions of the TZB could be removed and the balance of the H-frame constructed.

The Full Build approach to construction would construct the CRT deck concurrently and in advance of the highway decks. Gantry methods would be employed for constructing all three decks with full span post-tensioning of the segments.

At the Main Span, the decks are combined into a single large truss structure. It is anticipated that the floor beam trusses could be prefabricated and delivered by barge to the site either as single or multiple composite panels then lifted into position. Within this structure, the supporting deck for the CRT could be installed later.

Phasing of Construction

The construction of the CRT can be phased but at a significant increase in cost and construction duration. It would not be as efficient as constructing the CRT deck before the highway decks, and the additional cost and time would be significant.

The limited headroom of this option makes infeasible the use of a gantry to construct the CRT deck after the highway decks have been constructed. An alternate method of constructing the Final Build CRT would be to use balanced cantilever methods and employ low height hoists to winch up the segments from barges in the river. With post-tensioning required after each segment is placed, this method would be slow. To deliver the CRT segments, an additional round of dredging, with the same footprint as Initial Build dredging, would be required to clear deposition and provide adequate depth for the segment barges.

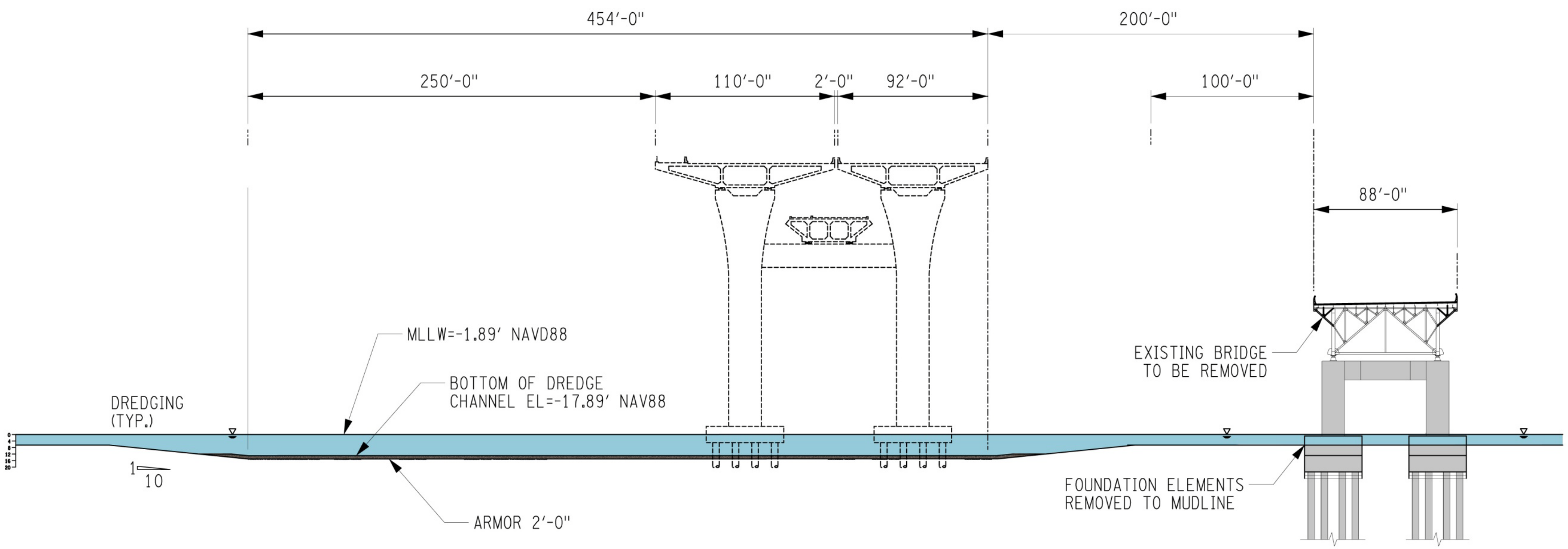


Figure 4.4 - Option 4 Initial Build Dredging

4.3.2 Option 5 – Two Structures - CRT Below

Options 5 and 6 make use of a traditional truss form for the two structures making up the crossing. The two planes of trusses supporting each of the two decks have a vertical depth that makes the structure very strong and very stiff over significant span lengths. This results in longer spans and thus fewer piers, leading to a greater structural efficiency for a given load. Trusses are typically made of steel, further improving the structure to weight ratio.

Replacement Bridge

Option 5 continues with the standard BRT/Highway decks, in this case located atop the trusses (Figure 4.5). The approach span length is in the order of 430 feet. In between the trusses and under the highway deck, in what is referred to as the lower bay, a concrete deck would be installed to carry the CRT. The north truss superstructure, which carries the CRT along with the Highway/BRT deck, would be stronger and stiffer than the south truss superstructure which carries only the Highway/BRT deck.

The truss superstructure is continuous across the length of the crossing. It is consistent between the approaches and the Main Span. The principal difference is that the approaches employ single column piers to support each truss structure, while the Main Span employs stays or hangers to support each truss structure. Because the depth of the structure has to provide for adequate CRT clearance, the overall depth of the truss cross-section is on the order of 37 feet.

On the approach to Westchester, the truss structures with their CRT and highway decks descend together as rapidly as possible (-1.97% grade). As they approach the shoreline, the truss structure without CRT can begin to curve upwards to locate the highway/BRT deck on top of the escarpment. The truss structure carrying CRT would extend the depth of the trusses to enable CRT to continue descending, while providing support for the highway deck above to curve upwards and likewise touch down on top of the escarpment.

Rockland Landing

At the Rockland landing, providing adequate clearance over River Road means that the highway/BRT decks will be significantly higher than the existing Thruway. Similar to Option 4, the highway and BRT lanes will be at similar elevation as the existing ground just east of the South Broadway Bridge. Shortly after crossing River Road, the truss structures will transition directly into an abutment, with the structure carrying CRT transitioning directly into a tunnel within that abutment.

Westchester Landing

Similar to Options 1-4, adequate separation is provided between the highway decks to enable the Bridge Station Connector to separate from the BRT/HOV/HOT lanes and come together in between the highway decks. As the CRT is not directly below, the BSC can make its separation further east, and the highway lanes do not need to rise quite as high for the BSC to pass under the westbound lanes (similar arrangement as Option 2). In the final portion of the approach, the depth of the truss supporting CRT and highway would deepen significantly to facilitate the different alignments taken by the highway and the CRT.

Construction Sequence

Again, similar to the other options, the south structure will overlap the existing TZB. A similar construction sequence will be employed.

Phasing of Construction

The truss structural form provided to support the highway/BRT decks also provides virtually all of the structural elements for the CRT with the exception of the deck to carry the CRT (Figure 4.6). This CRT deck, basically a concrete shell to carry the trackwork, maintenance way and power and signaling equipment can be pre-constructed and field bolted into place subsequent to construction of all the highway/BRT components.

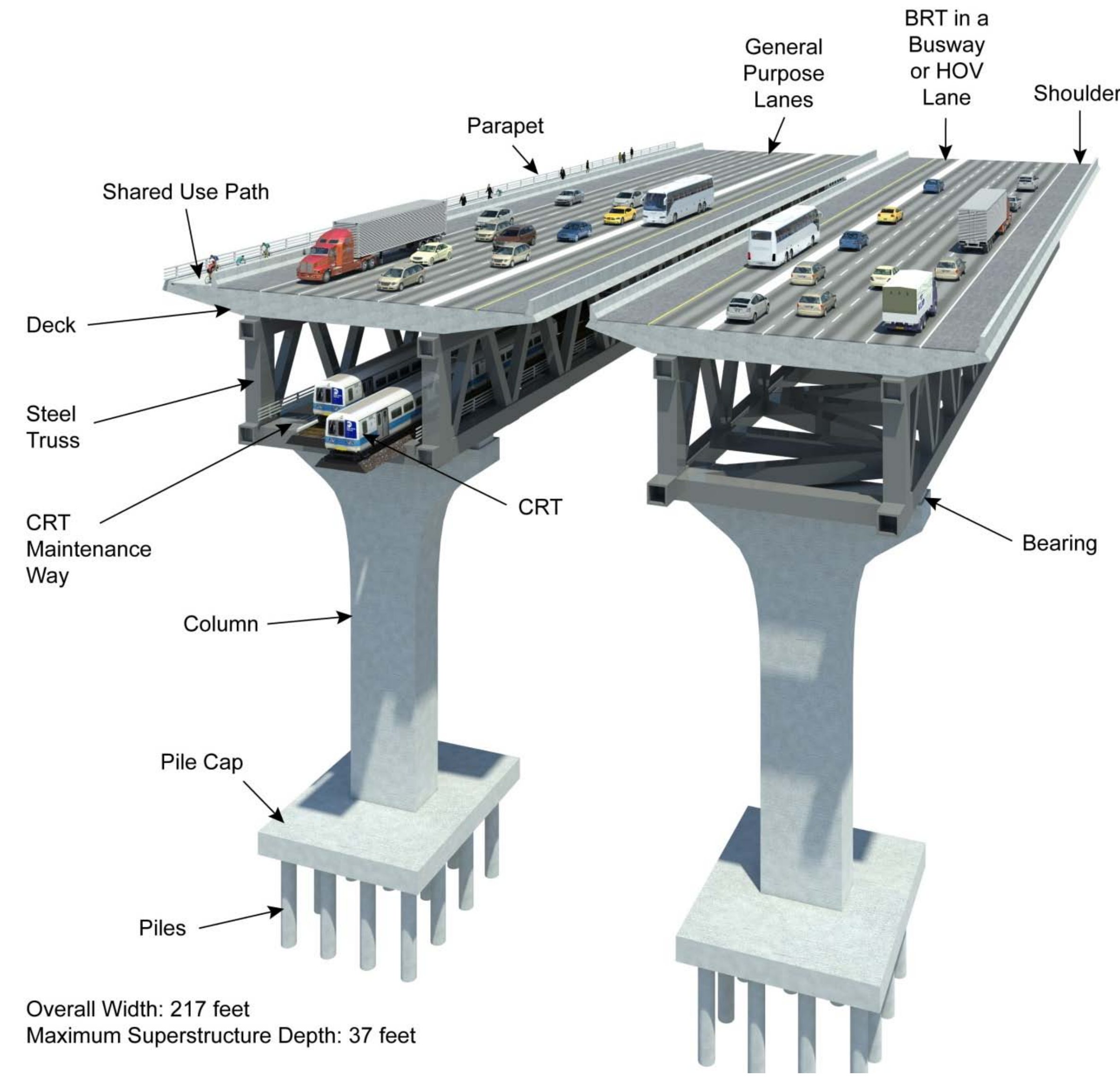
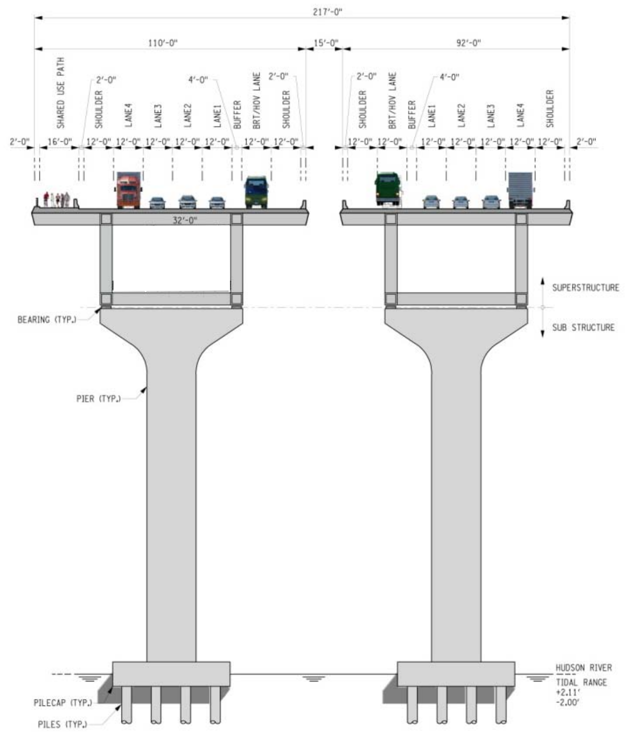
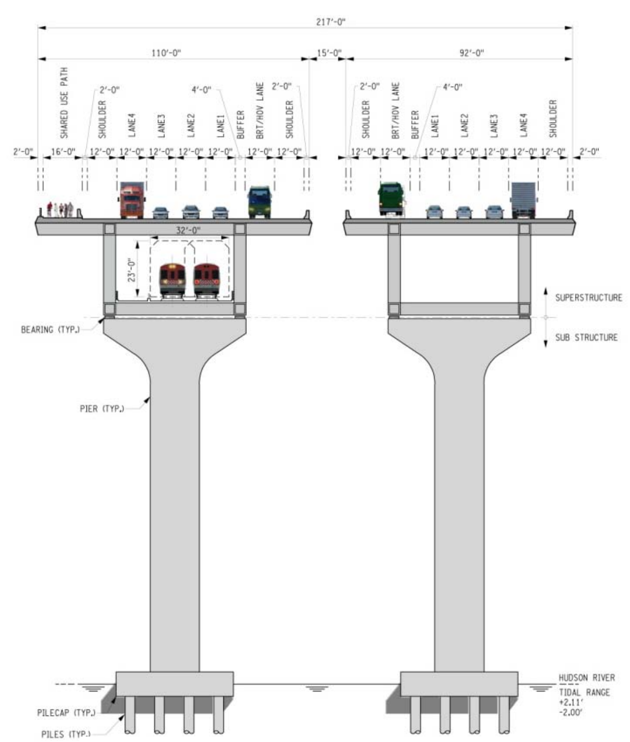


Figure 4.5 - Option 5 – Dual-Level CRT North Two Structures

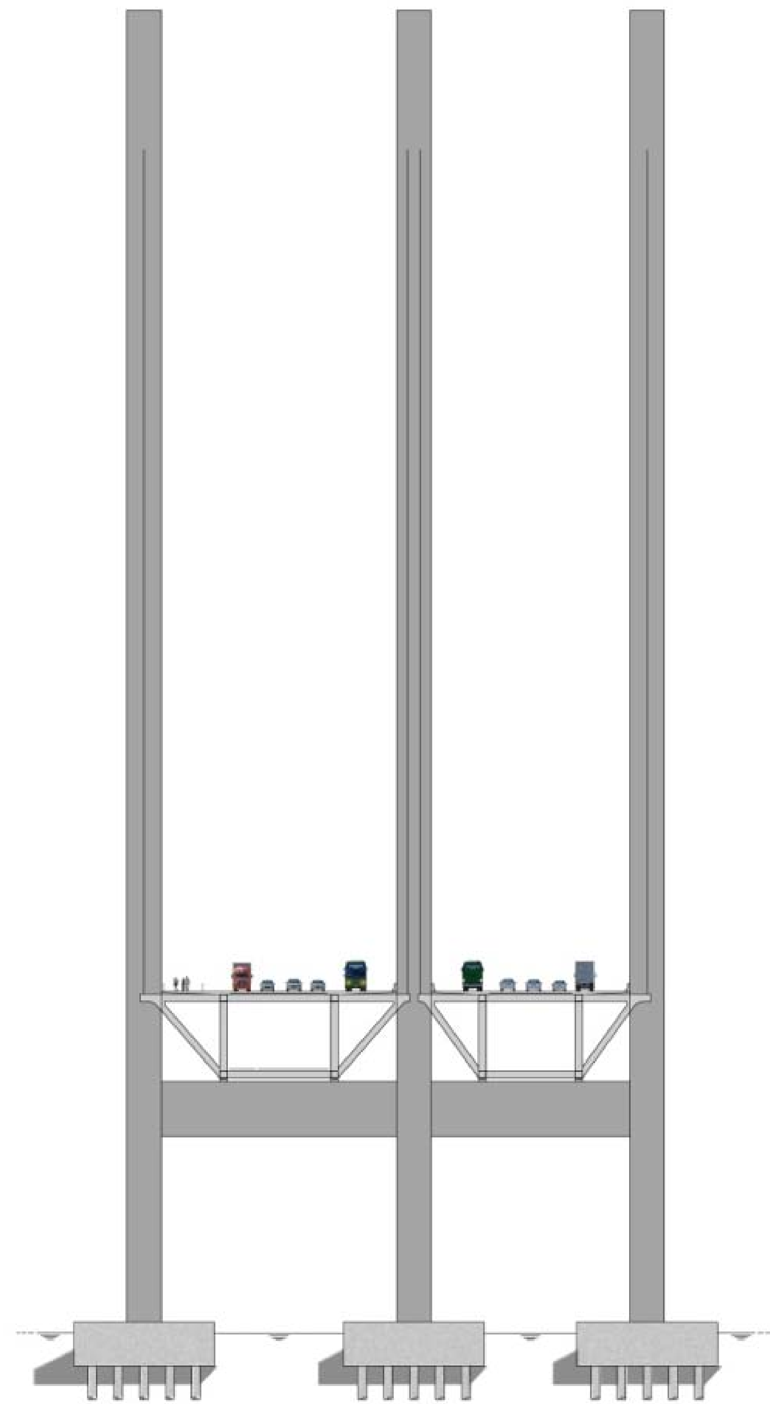


CRT Phasing Potential at Approach Span

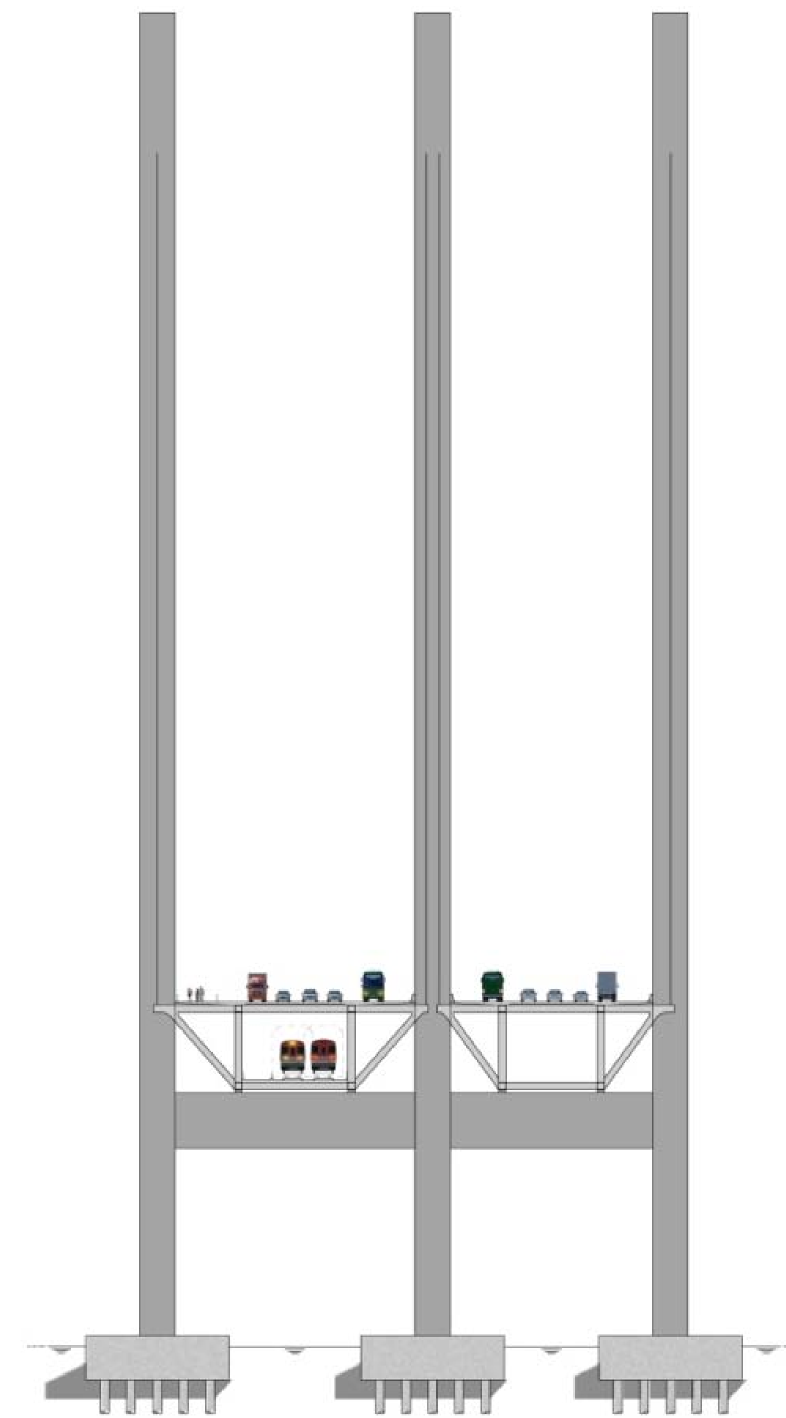


CRT added in Final Build

Approach Span



Initial Bridge Configuration assuming CRT to be implemented at a later date



CRT added in Final Build

Main Span

Figure 4.6 - Option 5 Configurations

Full Build Cable Stayed Option at Main Span

Full Build Arch Option at Main Span

Figure 4.7 - Main Span Options

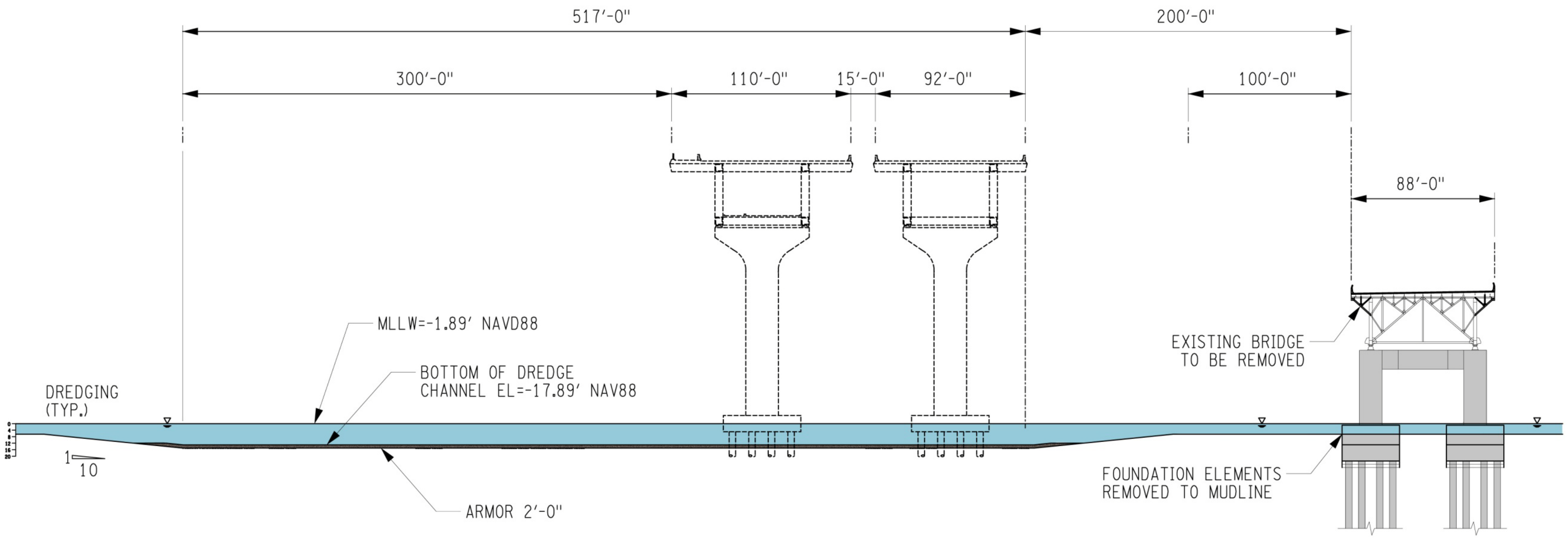


Figure 4.8 - Option 5 Initial Build Dredging

4.3.3 Option 6 – Two Structures – CRT and BRT Below

As described, Option 6 makes use of the traditional truss form for the two structures comprising the crossing. The form is generally similar to Option 5, however, both lower bays are employed to carry transit. It is significant to note that, this option does not support the BRT HOV/HOT lane alternatives, only the BRT Busway alternatives. Two tracks of CRT would be in one lower bay, while two lanes of BRT would be in the other lower bay. Without BRT, the highway decks above would be narrower. The north deck is 94 feet wide providing, during the temporary construction condition when all traffic is on the north structure, for either eight 11-foot lanes or seven 12-foot lanes employing the movable barrier.

CRT could be in the north or the south bay. BRT would be in the other bay. If BRT is in the south bay, it can pass under the Toll Plaza and come out on the south side of the Toll Plaza to connect into the ramps of the Tarrytown Connector. On the Rockland side, the BRT would pass out from under the highway lanes to the south and directly into a Busway along the south side of the Thruway.

Replacement Bridge

Option 6 would be the most compact of the suitable options (Figure 4.9). Its narrower highway decks reduce both the width and loads of the structures. The vertical depth of the structures would be the same as for Option 5. Like Option 5, the truss superstructure would be unchanged over the length of the crossing. Again, like Option 5, the substructure would consist of single column piers supporting each structure, while stays or hangers support the two structures over the Main Span.

Rockland Landing

Similar to Option 5, both structures will have to provide adequate clearance over River Road. This will place the highway decks at a significantly higher elevation than present. After crossing River Road, the highways will enter into a large abutment, while within the abutment, tunnels for the CRT and BRT would proceed inland. It is anticipated that the CRT tunnel would be pre-constructed to approximately the location of the South Broadway Bridge.

The BRT tunnel could take one of two forms. In one form, the BRT would pass to the south side of the Thruway, just west of Ferris Lane and quickly come up to the level of the Thruway. The busway would pass under the South Broadway Bridge and outside of the eastbound Interchange 10 on-ramp in a relatively deep cut. It would then pass under the Interchange 10 roundabout and emerge on the south side of the eastbound Interchange 10 off-ramp. This is the option that has been assessed for impacts and costed.

In its other form, the deep retaining walls alongside Interchange 10 would be avoided and the busway tunnel would be located directly under the highway lanes, through to Interchange 10. This form supports BRT in either the north or the south bay. Once past the Interchange 10 overpass, a transition structure would bring the BRT to the south side of the Thruway and under the eastbound Interchange 10 off-ramp. The busway would come up to highway elevation approximately 1,200 feet west of the Interchange 10 overpass. For both BRT connections, Hillside Road would have to be relocated slightly south and on a retaining wall to provide adequate space for the proposed busway.

Westchester Landing

On the Westchester side, the principal difference from all the other options is that the structures do not have to separate to provide for the Bridge Station Connector (BSC) to come together in the center then drop down under the westbound lanes. Both structures can stay adjacent as they come into the landing. The BSC can instead continue directly into the landing. If BRT is on the south, the BSC would curve south to emerge south of the Toll Plaza, where upon it would tee into the TTC. Alternately, the BSC can pass over the descending CRT to curve north into the proposed BRT station.

Construction Sequence

The construction would be staged similar to the other options with pre-construction of various tunnel boxes under the highway lanes to accommodate the CRT and possibly the BRT.

Phasing of Construction

In Option 6, final construction of both transit elements could be phased, though the expenditure phased would be minimal (Figure 4.10). As described for Option 5, provision of the truss system for the highway, provides most of the structural system for the CRT and in this case the BRT. The CRT deck, basically a concrete shell to carry the trackwork, maintenance way and power and signaling equipment; and the BRT deck, essentially two travel lanes and two shoulders can be pre-constructed and field bolted into place subsequent to construction of all the highway components.

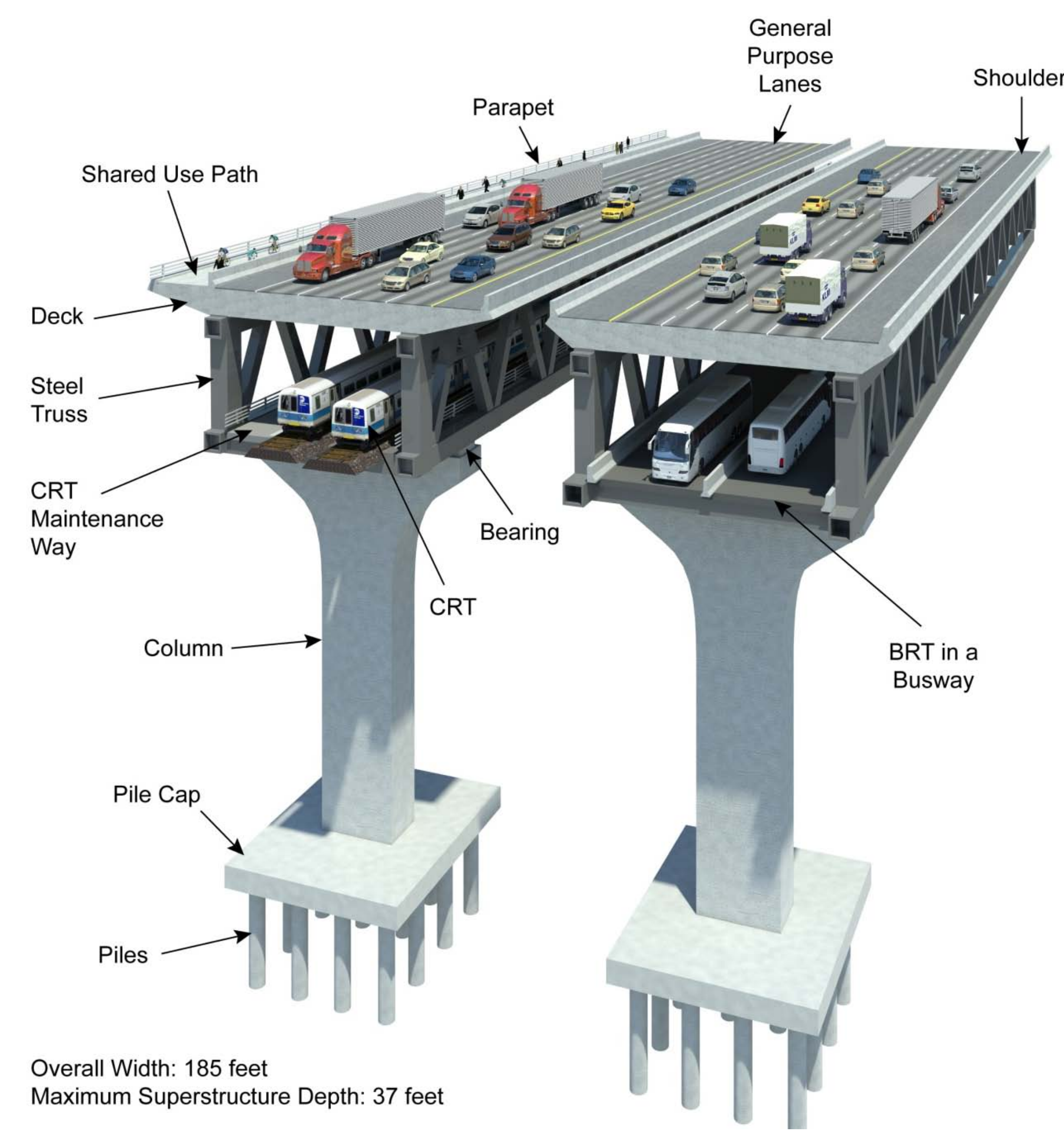
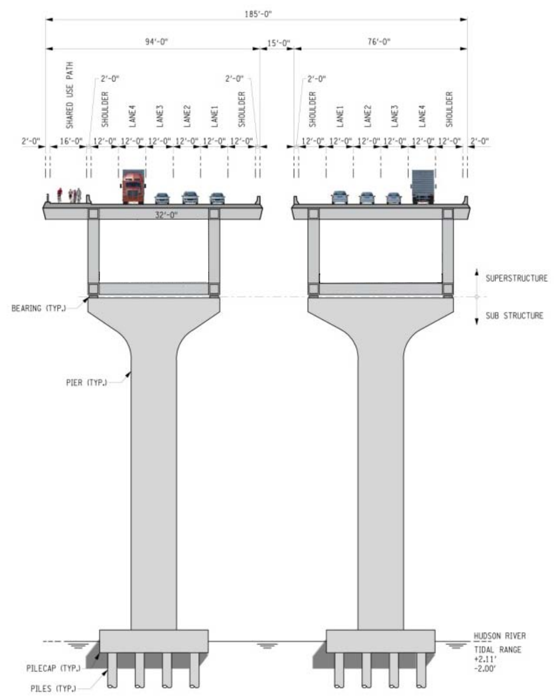
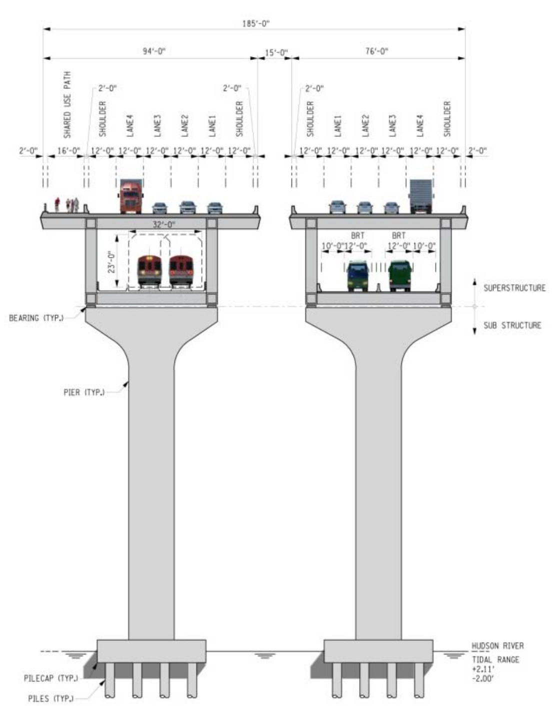


Figure 4.9 - Option 6 – Dual Level Transit Below Two Structures

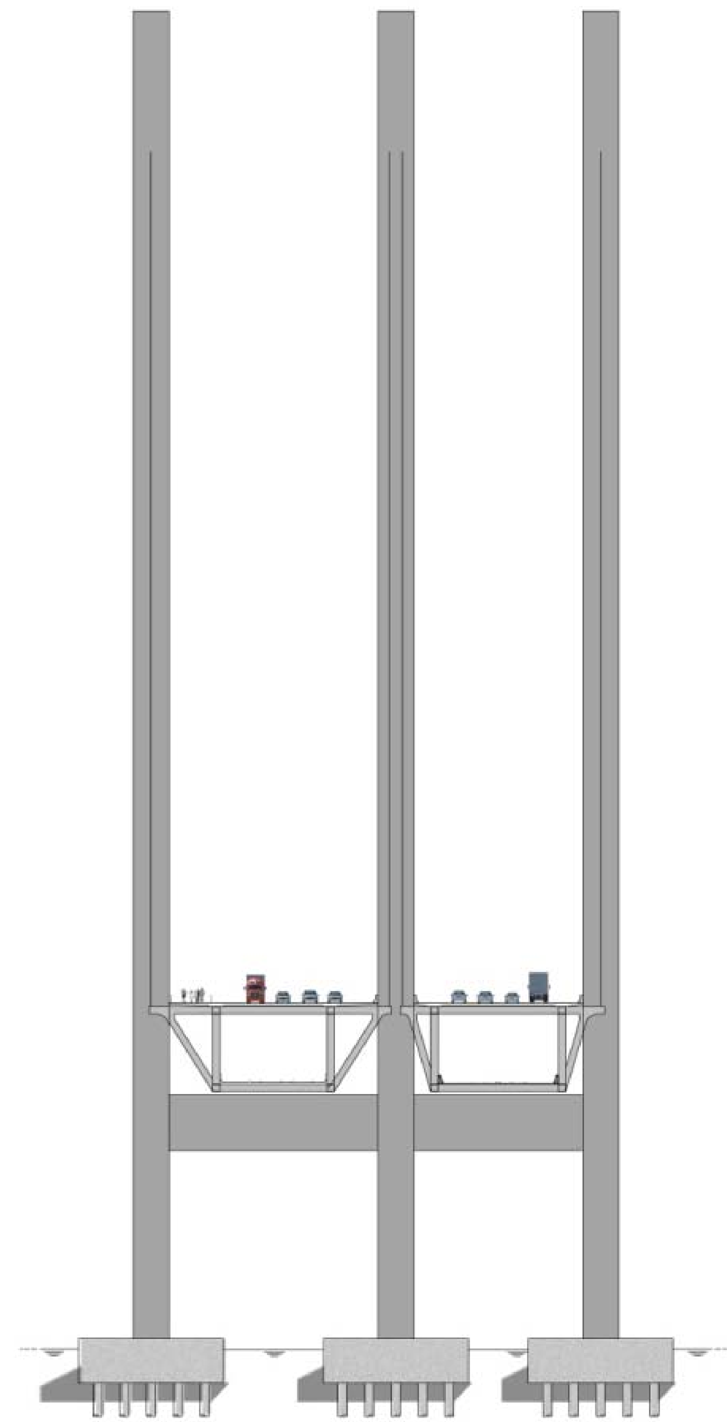


CRT Phasing Potential at Approach Span

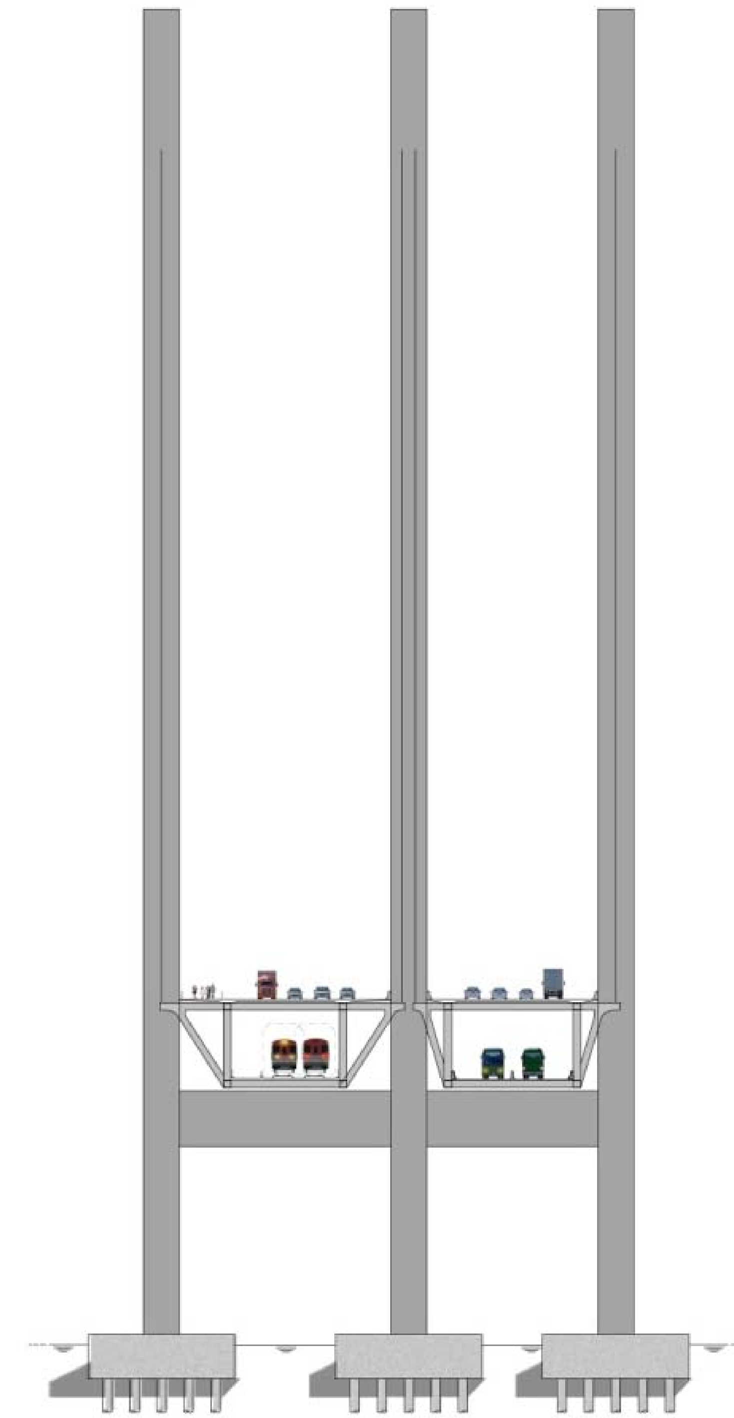


CRT added in Final Build

Approach Span



Initial Bridge Configuration assuming CRT to be implemented at a later date

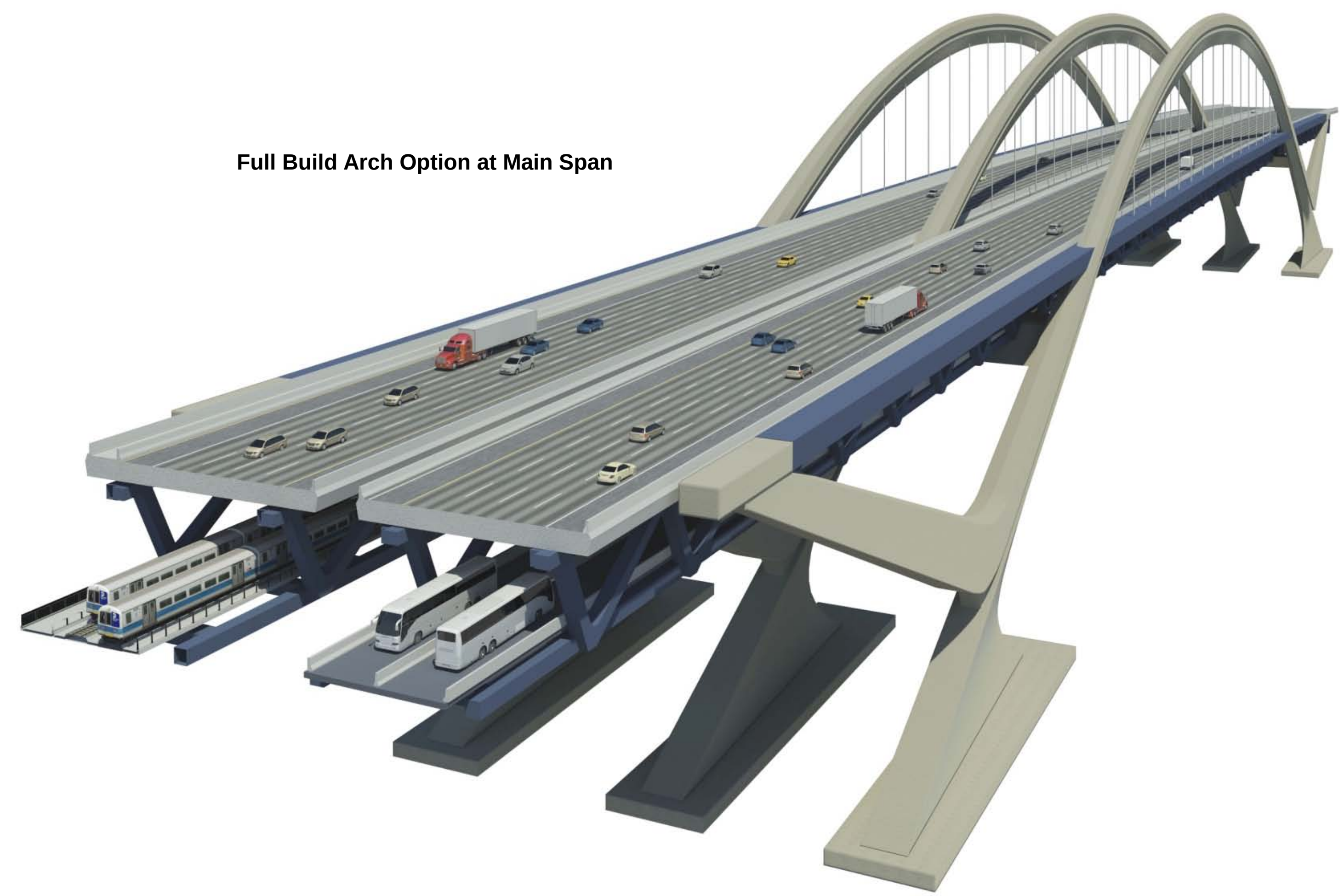


CRT added in Final Build

Main Span

Figure 4.10 - Option 6 Configurations

Full Build Cable Stayed Option at Main Span



Full Build Arch Option at Main Span

Figure 4.11 - Option 6 Main Span Options

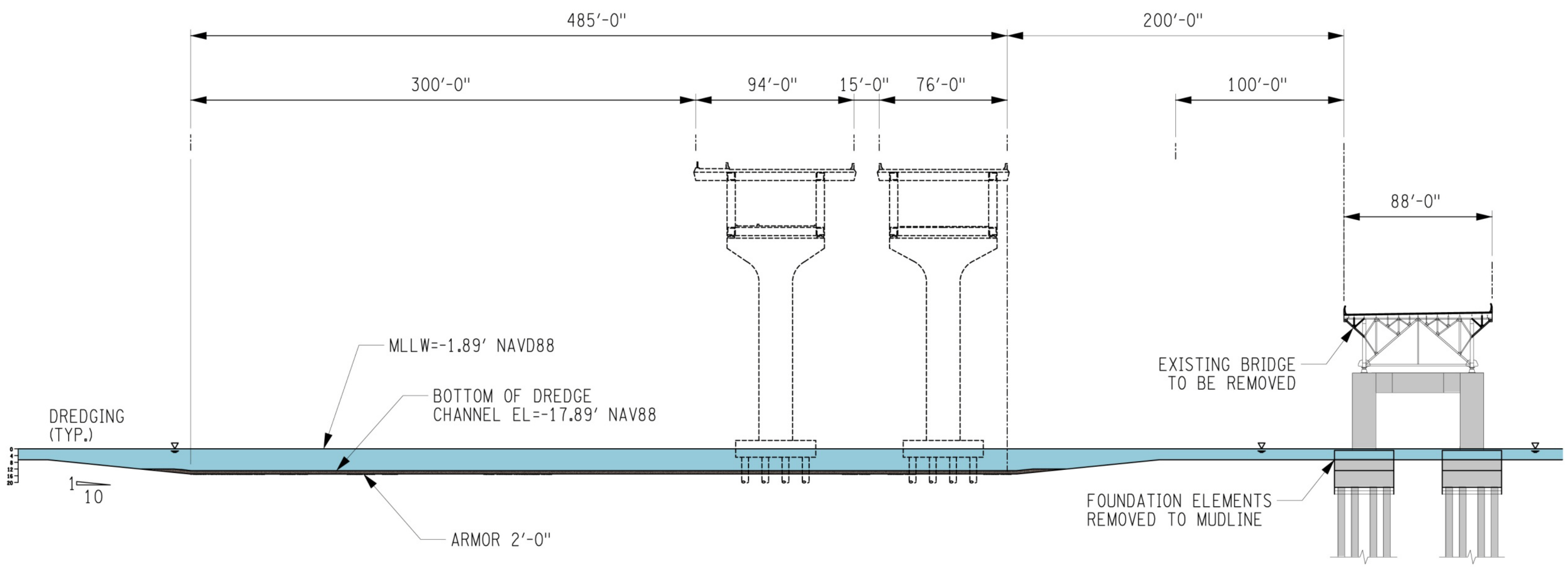


Figure 4.12 - Option 6 - Initial Build Dredging

4.4 Engineering Evaluation

This sub-chapter reviews the three dual-level options against the eight engineering criteria, each of which consider technical performance and compliance with codes, standards or agency requirements.

Engineering Criteria
Structural Integrity
Operations and Risk
Seismic
Redundancy
Emergency Response
Navigation
Life Span
Construction

4.4.1 Structural Integrity

Structural integrity is the degree to which the RTZB options would be in compliance with current structural performance requirements. For the purpose of this report, a service life of 150 years has been assumed. Details of the performance requirements are presented in Sub-Section 3.4.1 with only the comparison of options presented here.

Comparison of Options

Because the RTZB would be a new structure, all three dual-level options would be designed to meet current code requirements. Nevertheless, there are noteworthy differences between the options as a result of different internal structural actions, member sizes and overall structural performance that result in different material quantities, capital costs or maintenance requirements including:

- The structural form for Options 5 and 6 are similar but differ markedly from that of Option 4. In Options 5 and 6, the primary structural form is a truss that is a constant form from one end of the bridge to the other. Option 4 is comprised of one structural form in the Approach Spans (decks of segmental boxes supported on columns and transverse crosshead beams) but adopts another form (transverse trusses) at the Main Spans. The change in structural forms at the Main Spans for Option 4 reflects the inability of this option to directly support the lower CRT deck using stays or hangers or to accommodate a central tower leg to distribute the loads, as this tower would clash with the location of the CRT.
- The Main Span structural form in Option 4 is exceptionally wide with a transverse span between supporting cables of approximately 215 feet (greater than the deck width of 204 feet). This width requires transverse trusses underneath the road deck to support the roadways and CRT and to control deflections. The resulting deck structure is large and cumbersome and inefficient compared to the simple trusses used in Options 5 and 6. In Options 5 and 6, transverse trusses are not required though outriggers would be required to connect the main trusses to the supporting cables. In effect, due to the over-under arrangement of Option 4, its Main Span suffers from the absence of a central tower leg that could substantially reduce the quantity of material required for the deck.
- In the Approach Spans, the deck structure in Option 4 is deeper than Options 5 and 6. This truss form of Options 5 and 6 is approximately 37 feet deep from the top of the road surface to the bottom of the soffit of the lowest truss member. The total depth of the superstructure in Option 4, including the CRT deck, is 45 feet.
- Option 4 has almost twice as many piers in the Hudson River as Options 5 and 6. Option 4 has 50% more piles than Options 5 and 6 (Table 4.1).

	Option 4	Option 5	Option 6
Number of Piers	122	70	70
Number of In-River Piers	112	64	64
Number of Tower Legs	4	6	6
Number of Piles	2043	1364	1366
Number of In-River Piles	1968	1322	1322

Table 4.1 - Dual Level Options - Primary Substructure Components

Overall, Options 5 and 6 are more efficient dual-level structures. Both options take full advantage of the structural depth of the superstructure resulting in substantially longer spans with fewer numbers of piers. The structural economy of their steel trusses reduces the weight of the bridge and thus the number of foundation piles required, compared to the more massive concrete structure of Option 4.

4.4.2 Operations and Risk Assessment

The measure for this criterion is the performance of the RTZB in Normal, Natural, Accidental, and Intentional event scenarios. The objective is to identify those event scenarios where performance would differ between the options. Details of all of the 102 event scenarios considered are presented in Table C2 in Appendix C, with specific event scenarios ranging from the effects of wind on trucks or trains to the effect of intentional attacks on specific components of the bridge structure. The following highlights the more significant event scenarios and their implications.

Normal Events

Of the 24 events considered (see events 6-29 in Table E2) differences between options were identified in 4 events. The differentiating events included:

Event 13 and 22: Pavement or deck replacement
To provide clearance for the CRT in Option 4 only a box girder is suitable as the deck structure. Whether concrete or steel, the top slab of the box girder would be structural with limited potential for deck replacement. In options 5 and 6 it would be possible to design the deck for full replacement substantially improving the anticipated life span of the superstructure.

Event 17: Foundation and pier repair and maintenance in the Approach Spans
The proximity of the piers to the CRT in Option 4 would warrant temporary suspension of service on one of the CRT tracks during inspection or repair of the piers.

Event 21: Ability to access all components during deck inspection of the Approach Spans
For the box girder in Option 4 internal inspection would be required with the necessary safety precautions.

Two events noted as recurring and problematic for all dual-level options are Events 19 and 26, inspection of decks in the Approach and Main Spans, which require temporary suspension of CRT service in all options.

Natural Events

Of the 12 events considered (see events 30-41 in Table E2) differences between options were identified only in Event 31 – Wind on CRT vehicles. In this event, while all options would be subject to similar wind forces, CRT in Option 4 may be subject to local eddies generated by the interaction of the wind and the bridge. As a consequence, wind speed trigger levels for CRT speed restrictions or service suspension may be lower for Option 4. In Options 5 and 6, CRT is partially shielded from the wind by the surrounding trusses.

Accidental Events

Of the 46 events considered (see events 42-77 in Table E2) differences between options were identified in 2 events both associated with CRT derailment or fire. The differentiating events included:

Events 60, 62: Derailment of CRT or maintenance train in the Approach Spans
These events have in common train derailment; differing only in the type of train. In these events, all options have in common low-level containment walls to limit off track movements. However, the potential for trains to cross the containment walls cannot be eliminated and in all options secondary containment walls in the form of jersey barriers or similar would further contain derailment.

Beyond the effectiveness of these containment devices, any derailed trains in Options 5 and 6 that cross the jersey barrier would be contained within the structure by the adjacent trusses, which would be strengthened throughout to withstand collision. In Option 4 any train that crossed the jersey barrier would fall into the Hudson River.

Intentional Events

Of the 25 events considered (see events 78-102 in Table E2) no significant differences between options were identified. However, two events were identified as significant threats, though specific countermeasures are available to reduce risk.

Overall, 7 events resulted in differences between options none of which are considered of major significance. Notable in all options however, is the number of events that could potentially require temporary suspension of CRT service.

4.4.3 Seismic

The seismicity criterion is a measure of the seismic performance of the RTZB. As a 'critical' piece of infrastructure the TZB is required to meet the following performance levels:

- **Functional Event**: After a moderate seismic event the TZB should suffer no damage to primary members and be open for traffic within hours. A moderate event is defined as an earthquake with an approximate 500-year return period.
- **Safety Event**: After a major seismic event the TZB should have repairable damage and be open to emergency services within 48 hours and to general traffic within months. A major seismic event is defined as an earthquake with an approximate 2500-year return period.

All three options can meet these performance requirements with no major differences.

4.4.4 Redundancy

As outlined in Sub-Section 3.3.4 for the single-level options, the evaluation of redundancy is part of a larger risk assessment framework. The outcome of the overall risk reduction strategy would be a uniform level of risk across all the dual-level options.

In advance of the full risk assessment, it is apparent that there is a difference in the level of redundancy at the Main Spans for the dual-level options. In Options 5 and 6, there are eight tower legs in total compared to four in Option 4. While four tower legs in Option 4 can be acceptable (many long span bridge structures are constructed with just one central leg per tower) the level of redundancy is less than that of Options 5 and 6.

4.4.5 Emergency Response

Provision for emergency response would be included in all options including standpipe facilities and appropriate means to fight train electrical fires. Detailed emergency response plans would be developed in the course of final design and coordinated with the appropriate authorities based upon industry best practice. This criterion focuses on the ability of emergency services to access emergency events.

In all three Dual Level Options access to the highway and CRT decks would be via the Thruway. Access to the BRT deck of Option 6 would be by upland access into the busway. Should traffic be congested on the bridge, as a result of an auto accident, access for emergency vehicles would be along any of the traffic shoulders.

In Options 5 and 6, access to CRT tracks would be from emergency vehicles deployed on the westbound Thruway. Once near the incident, emergency personnel would access the CRT racks on the lower level via controlled access stairs located in between the two decks, at intervals of 200-400 feet. These stairs would provide access from the highway deck above to the CRT.

Similarly in Option 4, access to the CRT on the lower deck would be via stairs at similar intervals to those of Options 5 and 6. However, in Option 4 the stairs would have to be located on the outside of the highway structures adjacent to the outer shoulder in each direction.

Overall, emergency access is similar in all three options.

4.4.6 Navigation

The measure for this criterion is the level of conformance to navigational requirements of the US Coast Guard, who currently control the 600-foot wide and 139-foot high channel for shipping under the TZB. All options would accommodate these minimum dimensions for shipping.

At this stage in the Environmental Review process, the US Coast Guard has not changed these dimensional requirements but initial discussions indicate that some ships using the channel lower their uppermost equipment to pass under the TZB. Initial indication from the US Coast Guard is that an increase in the vertical clearance would be preferred, possibly to that of the Bear Mountain Bridge (155 feet), the next lowest clearance on the Hudson River. All options would provide the 155-foot vertical clearance.

4.4.7 Life Span

As outlined in Sub-Section 3.3.7, the life span of a bridge is the decision of the owner/operating agency that controls the maintenance regime. For the purposes of this report, maintenance and repair programs as well as consequent costs for each option have been developed to sustain the various crossing options for 150 years.

As also outlined in Sub-Section 3.3.7, one of the primary areas of concern that warrants full consideration of whole life costing is the durability of the deck. In Option 4, because the concrete box girder is an integral part of the overall structure, the ability to replace the deck in the future would be limited, and the value and composition of protection layers that minimize deck deterioration would warrant detailed study later in the design process, should this option be selected. This strategy for durability could differ substantially from that of Options 5 and 6, where the potential for full deck replacement would be possible.

4.4.8 Construction

This criterion identifies the type, scale and duration of construction and the potential phasing of CRT in line with the Tiering process for transit.

CRT Phasing

Figure 4.13 shows the CRT construction phasing potential for the approach spans of dual-level Options 4, 5 and 6. For Options 4 and 5, only the structure necessary to implement the highway and BRT lanes would be initially constructed plus any other structural components that would be impossible to construct at a later date. For Option 6, construction of the BRT roadway on the lower level could also be phased until a later date.

For Options 5 and 6, the Initial Build structures would be very similar and would include constrction of all substructure and superstructure elements with the exception of the CRT track box inside of the north structure, and for Option 6, the BRT roadway inside the south structure. With implementation of CRT, and for Option 6, the BRT as well, very little further construction would be required for these options and no further dredging would be required for Options 5 and 6.

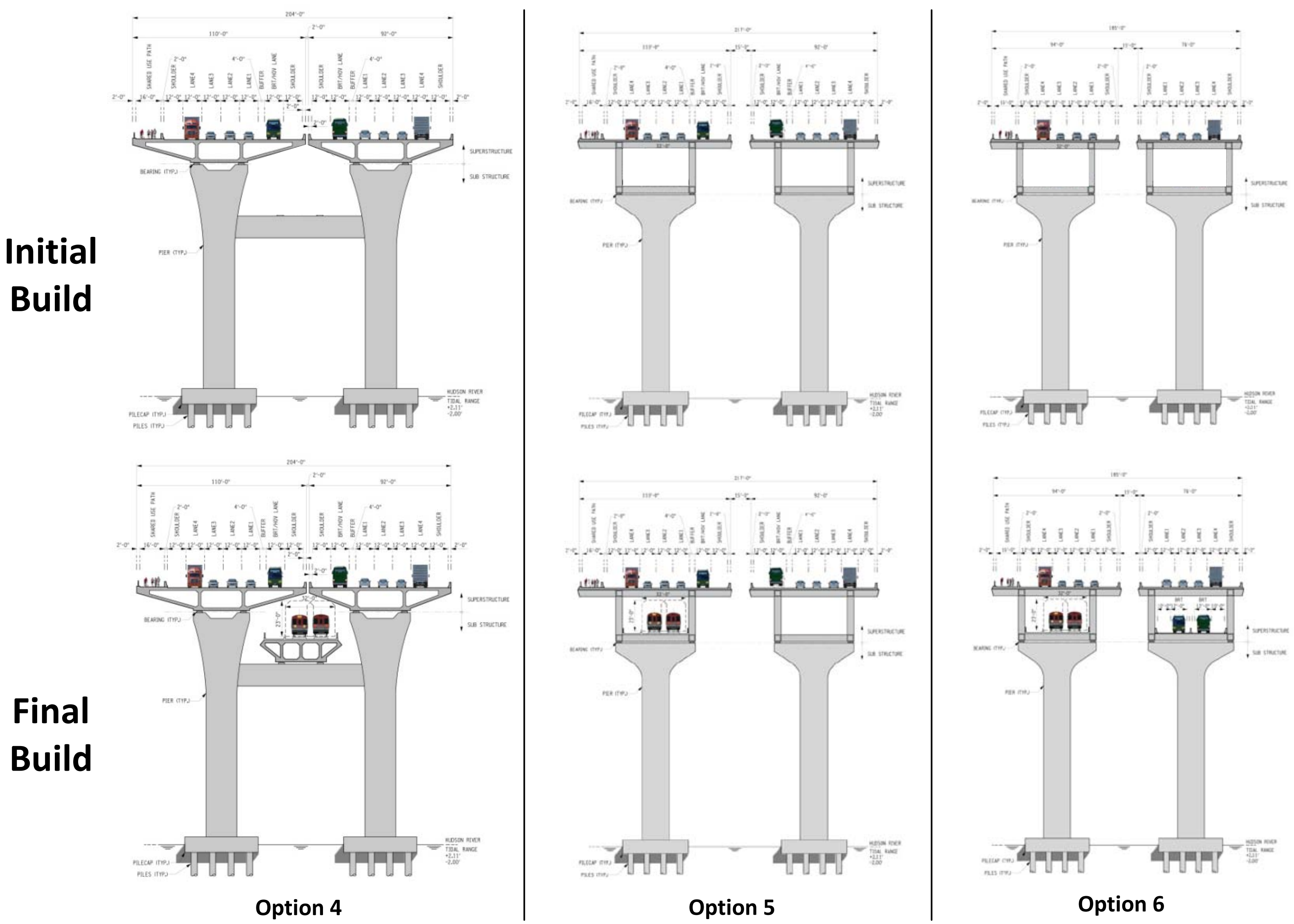


Figure 4.13 - CRT Phasing Potential for Dual Level Options

Construction Type and Scale

Options 5-6 are each of similar type and scale of construction. Each option incorporates the same type piles, piers and truss structure and differs only in the number of components. Option 4 has similar foundations and substructure to Options 5 and 6 but has a different superstructure form (box girders). Option 4 also has substantially more piles and piers compared to either Option 5 or 6.

The overall construction sequence for the replacement TZB would construct the south and north piers together progressing from the Main Span towards the shores. The south and north superstructures would closely follow. At the landings, the alignment of the south structure overlays that of the existing TZB. As a result, the north highway piers and superstructure would be constructed before the southern highway deck and piers at both the Rockland and Westchester landings reaching out approximately 2000 feet into the Hudson River.

The Final Build construction of Options 5 & 6 is relatively straightforward. CRT and BRT roadbed deck segments would be delivered from the landings along the ever lengthening constructed track and roadway and mechanically secured to the superstructure framing. The CRT track systems would then be installed.

The methods to construct the Final Build CRT for Option 4 are considerably more difficult with undesirable complications compared to Options 5 and 6. For Option 4, the constricted headroom over the CRT restricts and highly complicates the subsequent phased construction of the CRT deck. A number of construction methods have been explored. Because of the curves at both ends of the RTZB, it is not possible to launch the CRT deck from shore and push it to the Main Span. Because the headroom is so small, a conventional gantry cannot be accommodated. An under-slung gantry that hangs from the crosshead beam and supports the CRT deck segments above is a possible method. Because of the curves at both ends of the RTZB, this under-gantry would also have to be articulated, or a second purpose-built curved gantry would be required. Segment delivery would be from the landings along the already constructed trackway

An alternate method would be to construct the CRT deck using balanced cantilever methods. This technique could be employed for the curved segments eliminating the need for the curved gantry, or could be used for the entirety of the Approach Spans. Pierhead structures would either be formed and fabricated above the crosshead beams or lifted into place. Segments would then be lifted from barges then individually post-tensioned. To enable access for the barges bringing in segments, a Final Build round of dredging equivalent to the Initial Build dredging would be required along with near shore trestle structures. As the removal and disposal cost for a second round of dredging would likely exceed the cost of a bespoke curved gantry, this analysis has assumed gantry methods will be employed for placement of all CRT deck in Option 4.

Table 4.2 summarizes the extent of dredging for the dual-level options, all occurring during Initial Build and which differ by less than 15% between options.

	Dredge Parameters		
	Option 4	Option 5	Option 6
Structure width (feet)	204	217	185
Access channel width (feet)	250	300	300
Dredge width (feet)	453	529	498
Dredge volume (mcy)	1.52	1.74	1.64
Dredge area (acres)	142	163	153

Table 4.2 - Dredging Parameters for Dual Level Options

Construction Duration

The construction sequence for all options follows the same basic steps.

Construction initially commences in the deeper water near the main Hudson River channel and from there progresses towards both landings. As shown in Figure 18 the overall duration of Initial Build construction for Options 5 and 6 is similar at approximately 4.5 years, while the Initial Build duration for Option 4 is approximately 12 months longer largely due to the greater number of piers and complex construction at the landings. Final build construction for Option 4 is at least a year longer than the other options.

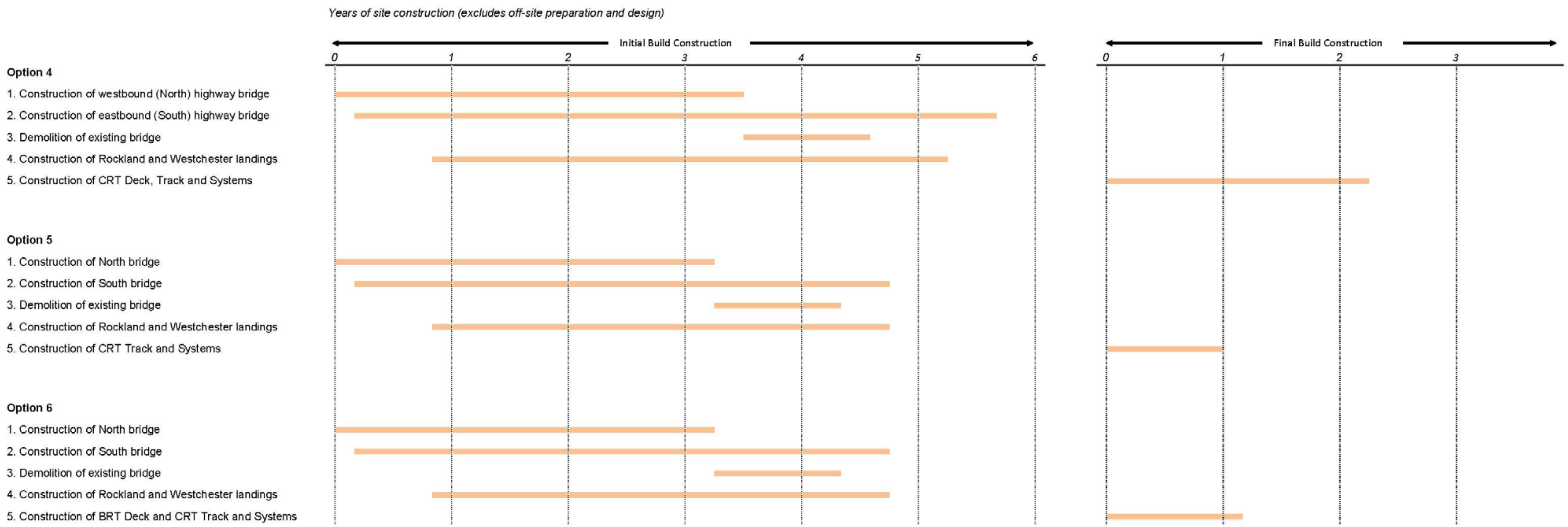


Figure 4.14 – Initial Build and Final Build Construction Duration for Dual Level Options

4.4.9 Summary of Engineering Criteria

Significant differences exist between Option 4 and Options 5 and 6. With CRT located in the center and under the highway decks, the Main Span for Option 4 cannot provide for a central tower. As a result, the entire load is supported on four outer towers. This creates an exceptionally large single non-redundant Main Span with a massive structural system to support both highway decks and the CRT deck. The considerable loads of this single span require exceptional towers in order to carry the combined loads. Both of these structural aspects and the lack of redundancy are very undesirable.

It is noted that the decks of Options 5 and 6 can be much more easily replaced than those of Option 4 greatly improving their lifespans. Wind is also a noted concern for Option 4, similar to Option 2. The containment of CRT within the trusses of Options 5 and 6 is also preferable in the event of a derailment; a level of redundancy that Option 4 cannot provide.

The phasing of CRT construction in Option 4 will require both straight and curved gantries, similar to Option 3, but in this case operating in an underslung arrangement. By contrast, the ability to phase construction of CRT in Options 5 and 6 is quite simple, though the overall savings are modest due to the limited scale of the elements that are phased (principally the CRT deck and the BRT roadway of Option 6). The Initial Build construction duration of Options 5 and 6 is shorter than Option 4 by a year. The Final Build construction of Options 5 and 6 is also shorter than Option 4 by at least a year.

Dredging quantities for Options 5 and 6 are 14% and 8% greater than the Full Build of Option 4 and Option 5 is 6% greater than Option 6.

The configuration and resulting complex structural system of Option 4 presents significant drawbacks across a number of engineering criteria when compared to the relatively standard truss structural system used by Options 5 and 6. The engineering criteria do not identify a differentiation between Options 5 and 6.

4.5 Transportation Evaluation

Transportation
Roadway Congestion
Alternative Modes
Mode Split
Transit Ridership
Non-Vehicular Travel
Reserve Capacity
Transportation System Integration

The transportation evaluation criteria are generally systemic in nature and measure effects that are system wide. The dual-level RTZB options all convey the same modes; however, they do not provide the same capacity for non-transit general purpose mode. Recalling that for BRT, the project alternatives include both Busway alternatives (B and C) and HOV/HOT lane alternatives (D and E), there is a difference in how the BRT lanes on the RTZB can operate. Option 6, with its exclusive Busway in the lower bay of the south structure is strictly a Busway alternative. For security reasons, non-BRT vehicles including HOVs in the general purpose traffic would not be permitted, indeed, would not be able to access this busway in the lower bay.

For the other dual-level RTZB Options, the BRT lane is adjacent to the general purpose highway lanes, separated by a painted 4-foot buffer. If a Busway alternative is adopted, it is anticipated that non-BRT vehicles will not be permitted to use this lane. This includes general purpose non-truck traffic with the requisite HOV occupancy, and may even include non-BRT system buses. Short of illegally crossing the painted buffer, the direct connection between the upland Busway and the BRT lane on the RTZB will not provide for access from the general purpose lanes into this lane. All non-BRT traffic is thus constrained to the 4 general purpose lanes provided in each direction.

If an HOV/HOT lane alternative is adopted, it is anticipated that BRT vehicles will share this lane with candidate HOV vehicles with requisite occupancy, and possibly with non-truck single-occupancy vehicles (SOVs) that are willing to pay a toll, whose price will vary in order to provide a suitable travel speed for the lane by limiting the number of non-transit vehicles using it. To access this lane, slip ramps between the leftmost general purpose lane and the HOV/HOT lane would be provided.

Having HOV/HOT lanes provides Options 4 and 5 with additional capacity (on the order of one-half of a travel lane) for general purpose non-truck traffic with the requisite HOV occupancy or that are willing to pay the toll to use the HOV/HOT lane. The ability of these HOV and toll-paying general purpose vehicles to use the HOV/HOT lane increases the overall capacity available to all general purpose vehicles for Options 4 and 5. As a result, transportation criteria are a differentiator in the selection of RTZB options.

The supporting elements (shoulders, speeds, etc.) are the same across all options.

4.5.1 Roadway Congestion

As described above, the BRT Busway alternatives provide less capacity for general purpose traffic than the BRT HOV/HOT alternatives. With less capacity for this traffic group, roadway congestion for a given level of demand will be higher for the BRT Busway alternatives. Options 4 and 5 provide for operation of the BRT lane as either a BRT Busway or as a BRT HOV/HOT lane. Option 6 does not, providing only for BRT Busway operations.

The consequent greater roadway congestion of the BRT Busway alternatives may thus be potential differentiator in the selection of project alternatives, and thus a differentiator in the selection of the RTZB options.

4.5.2 Alternative modes in mixed traffic

Again, as noted above, under the BRT HOV/HOT alternative (available for Dual Level Options 4 and 5), BRT buses would share the HOV/HOT lane with a limited amount of general purpose traffic with the requisite occupancy, or that have opted into the HOT lane by payment of a toll. Option 6, configured to support Busway alternatives only, would not experience alternative modes in mixed traffic. Busway alternatives (which include all Dual Options 4-6) would not permit non-BRT vehicles to use the BRT lane on the RTZB. Because it is possible to preclude the presence of alternative modes in mixed traffic by adopting the Busway Alternative, it is not a differentiator.

4.5.3 Mode Split

Mode split would not be different under any of the three dual-level options.

4.5.4 Transit Ridership

Transit ridership would not be different under any of the three dual-level options.

4.5.5 Non-vehicular travel

As an equivalent SUP would be provide for all options, non-vehicular travel would not be different under any of the three dual-level options.

4.5.6 Reserve capacity

With the exception of Option 6, all options provide 4 general purpose traffic lanes, a fifth BRT lane, and two shoulders in each direction. Conversion of any of these elements to general purpose roadway is possible and would be equally feasible under Options 4-5. Option 6 could conceivably convert the two lanes and two shoulders of the BRT system into directional capacity through reversible connections at both ends of the RTZB. Mitigating against the slightly higher reserve capacity of Option 6 (two shoulders) is the significantly greater difficulty that would be involved developing the reversible connections described. This suggests that Options 4 and 5 would have higher reserve capacity that could be practically developed.

As Options 4 and 5 could practically provide larger reserve capacity than Options 6, reserve capacity is a differentiator in favor of Option 4 and 5.

4.5.7 Transportation System Integration

Option 6 does not support the BRT HOV/HOT alternative. It only supports the BRT Buslane alternative. Were a decision made to operate the BRT system as HOV/HOT system Option 6 would not have a means to sustain an HOV/HOT lane designation over the RTZB. Transportation system integration is a differentiator adverse to Option 6.

4.5.8 Summary

All Options have identical capacity under the Busway Alternative, and Options 4-5 have identical capacity under the HOV/HOT Alternative. Options 4 and 5 have greater potential reserve capacity. As noted, Option 6 does not support the BRT HOV/HOT Alternative.

Transportation Criteria is a differentiator in favor of Options 4 and 5 based upon their flexibility to provide for both the BRT Busway alternatives and the BRT HOV/HOT lane alternatives.

4.6 Environmental Evaluation

The bridge replacement options have been evaluated using several key environmental criteria. The criteria encompass both the natural and built environment and the evaluation is focused on impacts within a study area bounded on the west by Interchange 10 in South Nyack and on the east by Interchange 9 in Tarrytown.

Environmental	
Construction	**Operation**
Displacement Acquisitions	Land Use
Historic Resources	Displacement Acquisitions
Archeological Resources	Historic Resources
Parkland 4(f)	Archeological Resources
River Ecology	Parkland 4(f)
Community Noise	River Ecology
	Avifauna
	Visual

4.6.1 Land Use

Land use criteria as applied to environmental assessments typically focus on the consistency of proposed projects with local land use policy, as expressed in zoning and other land use policy documents such as master plans, coastal zone management plans, and urban renewal plans. While zoning codes regulate the permitted use, bulk, and other attributes of projects (site layout, design, parking, etc.), state highway projects are not subject to such local ordinances and highway characteristics are not usually addressed in zoning. However, highway projects may have land use consequences, both direct and indirect. For example, land uses (residential, commercial, industrial, etc.) may be displaced, and highways may alter the character of a neighborhood or may induce new development, desired or otherwise. Acquisitions and displacements are addressed separately in Section 4.6.2.

In the context of assessing various bridge options, land use criteria are focused on (1) the project's consistency with local land uses and land use policy and (2) on the potential for transit-oriented development (TOD).

Rockland

In Rockland, the relevant local communities are the villages of South Nyack and Grand View-on-Hudson. Grand View-on-Hudson is a narrow 2.5-mile long strip of Hudson River waterfront; its northern border is South Nyack at the TZB landing. Zoning ordinances in these communities do not address the TZB. Neither community has a master plan. Grand View is zoned exclusively residential and South Nyack is almost exclusively residential. South Nyack has attempted to extend public waterfront access (e.g., the recently developed Gesner Avenue Park at the water's edge). Thus, plans to include a SUP on a new Tappan Zee bridge would appear to be consistent with such policies to facilitate public access to view the river. The bridge SUP would be accessed from local streets in South Nyack. As all options provide for a SUP, this element is not a differentiator among options.

During construction of all bridge options, the South Broadway bridge connecting areas north and south of the Thruway, would be closed for approximately 10-18 months. The potential alignment may result in additional displacements and acquisitions to properties located along Cornelison Place, Smith Avenue, Elizabeth Place and South Broadway, and would likely alter the land use character of this low-density neighborhood. However, given that all options require the closing of this bridge, this element is not a differentiator among options.

With respect to TOD in Rockland, all RTZB options provide equivalent capacity and facility for transit, thus, there is an equivalent potential for TOD for all dual-level options.

Land use implications are not a differentiator among the dual-level options in Rockland.

Westchester

In Westchester the relevant local community is the Village of Tarrytown. Tarrytown has a 2007 comprehensive plan, a zoning ordinance and a Draft Waterfront Revitalization Plan (which still must be approved by New York State). Tarrytown's Comprehensive Plan describes the TZB project status and states that the Village intends to work with officials to mitigate any negative impacts to the village. The plan recommends that Riverwalk remain uninterrupted where it currently is planned to pass beneath the existing bridge. Tarrytown's zoning ordinance does not address the TZB; however, permitted uses in the vicinity of the bridge include a variety of commercial and high density residential uses, resulting in a secondary commercial center, as compared to its traditional downtown near the Tarrytown Station. The village's Draft Waterfront Revitalization Plan emphasizes achieving public access to the waterfront. Construction of a SUP on a replacement bridge would be consistent with this plan and would connect with the already partially constructed Riverwalk project in Tarrytown to provide a continuous esplanade along the Tarrytown waterfront. All options provide for a SUP, so this element is not a differentiator among options.

Land use implications are not a differentiator among the options in Westchester

4.6.2 Acquisitions and Displacements

The dual level options are similar in their potential to displace properties (Table 4.3). All dual-level options would displace two properties in Rockland. No displacements would occur under any of the options in Westchester County.

Initial Build and Final Build Configuration (same)			
Screening Criteria	**Option 4**	**Option 5**	**Option 6**
Number of Displacements (Rockland County only)*	2	2	2
Number of Dwelling Units (Rockland County only)*	3	3	3
Permanent Acquisitions in Acres In Rockland	0.18	0.18	0.01
Permanent Acquisitions in Acres in Westchester County	0.31	0.31	0.07
Construction			
Screening Criteria	**Option 4**	**Option 5**	**Option 6**
Easements in Acres In Rockland	0.19	0.19	0.07
Easements in Acres in Westchester County	0.44	0.43	0.28

* There are no displacements in Westchester County

Table 4.3 - Displacements and Acquisitions for Dual Level Bridge Options

Acquisitions and displacements are not a differentiator among the dual-level options.

4.6.3 Historic Resources

As noted in Table 4.4, the direct impacts of Options 4, 5, and 6 do not result in potential displacements of historic architectural resources, and Option 5 has no direct impacts. The three options would indirectly impact the same historic architectural resources (Table 4.5). The Visual Resources section (4.6.8) concluded that Option 6 would have the least adverse visual effects because it would be supported by fewer columns, have a more shallow profile, and a narrower bridge structure. In summary, although Option 5 would not result in direct impacts to historic architectural resources, and Option 6 would result in direct easement impacts to one resource, Option 6 has the least potential to affect historic architectural resources because it is the most preferable from an indirect visual perspective.

Historic resources are a differentiator among the dual-level options.

4.6.4 Archaeological Resources

In Rockland County, all options would have direct impacts to previously identified and potential archaeological resources. All options would impact previously identified New York State Museum (NYSM) Site 6402. However, Option 6 would have the fewest direct impacts to potential archaeological resources, while Options 4 and 5 would have the most direct impacts. Under all three options, the areas of archaeological sensitivity that may be directly impacted include Elizabeth Place Park, the front and side yards of two structures on Elizabeth Place and Broadway and the yard areas of several structures along the southern I-287 ROW between Broadway and Bight Road.

In Westchester County, there are no previously identified sites that would be directly impacted by any of the Dual Level Options. The area inboard of the Metro-North ROW is a previously undisturbed area, which is sensitive for prehistoric archaeological remains. All options would impact this area.

Within the Hudson River, the various Options would directly impact the bed of the river, and therefore, any potential archaeological resources that may be present. Research on the archaeological potential of the Hudson River bottom, is on-going as part of the Section 106 compliance study for this project.

Archaeological resources are not a differentiator among the dual-level options.

Option 4	Option 5	Option 6
ROCKLAND		
RNRE 321 South Broadway (easement)	None	RNRE 78 Smith Avenue (easement)
WESTCHESTER		
None	None	None

Table 4.4 - Direct Impacts to Historic Resources - Dual Level Options

ROCKLAND	WESTCHESTER
• RNRE South Nyack Historic District • RNRE 78 Smith Avenue • RNRE 321 South Broadway • RNRE 10 Ferris Lane • RNRE 4 Salisbury Place • RNRE 5 Salisbury Place • NRL Wayside Chapel • RNRE River Road Historic District	• NRL Tarrytown Lighthouse • NRE Tarrytown Railroad Station • RNRE Tappan Landing Historic District • RNRE Irving Historic District • RNRE Hudson River Railroad • NHL Lyndhurst • NHL Sunnyside • NRE County Waterfront Park • RNRE South End Historic District • RNRE Matthiessen Park Historic Buildings • NRE Irvington Historic District

Table 4.5 - Historic Resources with Indirect Visual Impacts

4.6.5 Parklands / 4f

Potential effects to parklands are an important consideration because they would typically require an analysis under Section 4(f) of the Transportation Act. This analysis would require, among other elements, an assessment of avoidance alternatives. A requirement that no other feasible and prudent alternative exists is required, unless the park operator concurs that the impacts to the affected resource are negligible and/or that there would be a net benefit to the resource as a result of the project.

There is one affected park in the area of the TZB landings (Elizabeth Place Park) and a small (unnamed) seating area across from this park on South Broadway, in South Nyack, Rockland County. These small neighborhood resources (approximately one acre) would be affected by all options by requiring acquisition of a strip of its northern boundary with the Thruway.

In conclusion, Parkland/4f issues are not a differentiator among the dual-level options with respect to parklands but are a differentiator for historic resources.

4.6.6 River Ecology

Option 4 differs substantially from Options 5 and 6 with regards to the pier/foundation spacing. The reduced structural depth of Option 4 leads to shorter spans and an increase in the number of piers/foundations.

Options 5 and 6 have similar structural designs, and differ primarily in terms of where the BRT system is located. Option 5 locates the BRT system on the same level as the highway elements, thereby expanding the width of the bridge deck in comparison to Option 6, which locates the BRT system on the lower level. In river impacts of the dual-level options are compared in Table 4.6.

Shading of River

Option 6 reduces the total surface area of the bridge by placing the BRT system on the lower level. Shading area of the river is reduced by 18 to 16% when compared to Options 4 and 5. Shading of the river is considered a differentiator.

Stormwater Quality

The impervious area calculated for storm water quality purposes includes the RTZB deck area over the land. Option 6 has 19 to 16% less impervious surface when compared to Option 4 and 5. This reduction in impervious surface is approximately proportional to the reduction in impacts. Stormwater quality is considered a differentiator.

Permanent Loss of Habitat

All options result in a net increase in habitat once the existing TZB is removed (yielding 5 acres of reclaimed habitat). The difference in habitat gained is only 0.3 acre. Relative to the extent of river bottom habitat in the Tappan Zee estuary, permanent loss of habitat is not considered a differentiator.

Volume of Water Displaced

Options 5 and 6 have similar structural designs leading to similar volumes of water displaced (32.7 acre-feet). Option 4 has the greatest water displacement due to shorter foundation/pier spacing with a 7% increase over Options 4 and 5. Relative to the volume of water available in the Tappan Zee estuary, Volume of water displaced is not considered a differentiator.

Wetlands

Option 6 has a virtually negligible effect on marginal wetlands located along the Rockland shore, while Options 4 and 5 do not impact wetlands. The small area is not considered a differentiator.

In-river Habitat

The addition of hard substrate to the river is considered a positive, habitat producing effect. Due to the greater number of foundations, options 4 would provide 38% more habitat area than the other options. In-river habitat is thus considered a differentiator.

Underwater Acoustic Impacts

Options 5 and 6 require a similar number of in-river foundation piles (1322). Option 4, however, requires a significantly greater number of in-river piles (1968) due to the difference in foundation/pier spacing and structural mass. The need for 49% more piles for Option 4 compared to Options 5 and 6 represents a significant increase in acoustic impacts during pile driving, and may represent a potentially greater impact to aquatic resources. Underwater acoustic impacts are considered a major differentiator against Option 4.

Suspended Sediment

The volume of dredging required in the dual level bridge options varies from 1.52 to 1.74 mcy. Based upon an anticipated 1% loss, suspended sediment loads are expected to range from 17.4 tcy for Option 5, to 16.4 tcy for Option 6 and down to 15.2 tcy for Option 4. These volumes are directly related to construction methods, which are similar for Options 5 and 6. Option 4 requires a smaller dredging volume (13% less) due to the construction techniques applicable to its shorter pier spans. Suspended sediment is considered a differentiator among the dual-level options.

Temporary Loss of Habitat

Differences in the temporary loss of habitat between bridge options are influenced most heavily by the area of the dredge prism. In-river construction access and mooring facilities are expected to be similar regardless of the Bridge Option. Dredging area, however, is reflective of the type of barge movements and the construction methods that are necessary to the construct a specific bridge type. Option 4 requires least amount of initial dredging while Option 5 requires the most dredging. Temporary loss of habitat is considered a differentiator.

Duration

Construction duration is closely tied to the number of individual elements that need to be constructed. It is also a measure of the cumulative daily impact of construction operations including noise, dust, traffic and other nuisances. Option 4, which has significantly more bridge piers than Options 5 and 6, is scheduled to take 1½ years longer (5.5 years versus 4.0 years) to construct. Construction duration is a significant differentiator.

Summary of In-River Impacts

As was the case for single-level options, the comparison of potential impacts provided here (Table 4.6) for dual level structures is a relative comparison, not a conclusion with respect to absolute impacts. When considering long term and construction effects, Options 5 and 6 potentially have fewer impacts than Option 4, particularly with respect to underwater acoustic impacts and duration of construction. However, there is not a clear differentiator between Options 5 and 6.

Consequently, potential impacts to Hudson River Ecosystems and Water Resources can be considered a differentiator adverse to Option 4, but not between Options 5 and 6.

Initial and Final Build Configuration (same)			
Screening Criteria	**Option 4**	**Option 5**	**Option 6**
Shading of River (acres)	72.3	70.2	59.3
Impervious Surface / Stormwater Quality (acres)	77.6	74.8	63.1
Permanent Loss of Habitat (acres)	4.6	4.3	4.3
Volume of Water Displaced (acre-feet)	35.0	32.7	32.7
Wetlands (acres)	0	0	0.03
In-river Habitat (vertical surface area – acres)	5.5	4.0	4.0
Construction			
Screening Criteria	**Option 4**	**Option 5**	**Option 6**
Underwater Acoustic Impacts (no. of in-river piles)	1968	1322	1322
Suspended Sediments (volume in thousand cubic yards)	15.2	17.4	16.4
Temporary Loss of habitat (acres)	142	163	153
Duration (years)	5.5	4.5	4.5

Table 4.6 - Ecological Comparison of Dual Level Options

4.6.7 Avifauna

A concept for the replacement bridge's Main Span has not yet been selected (e.g. a cable stay or arch). Based on the current level of conceptual design information it is expected that a cable-stayed Main Span would have the same approximate proportions (tower height and cable array width) for the three dual-level bridges. Furthermore, it can also be expected that the width and breadth an arch main span would be similar for the single-level bridges. Similarly, cable-stay or arch spans are likely to have the same approximate proportions for the dual level bridge types.

With regard to avifaunal impacts, an arch main span is expected to have less potential for bird strike impacts than a cable stayed main span. However, since the two span types are applicable to bridge configurations being evaluated herein, impacts to avifauna are not considered a differentiator in this analysis.

4.6.8 Visual

The visual criteria and observations on visual context and viewer reactions, as described under the Single Level Options, also hold for the dual-level options (i.e., the new bridge would be wider, taller in profile along the western causeway, and have deeper deck structure than the existing bridge). All dual-level options would be more intrusive in their visual context than the existing bridge, especially to viewers near to the landings and north of the existing bridge. However, the reduction in the number of columns and the relocation of the RTZB to the north will improve visual conditions for some viewers, including boaters and residents to the south of the landings. Moreover, the distances involved and frequently obscured sight lines (due to trees and homes) will ameliorate the adverse impact of these changes to most viewers.

With the dual-level options, the number of columns varies (Table 4.7), with Option 4 having 68 piers of 2 columns each and Options 5 and 6 having 33 piers of 2 columns. Option 4 would also have the deepest deck structure, with CRT located below and between the two vehicular decks, whereas Options 5 and 6 have their lower decks directly beneath the vehicular decks, providing for an overall narrower bridge than Option 4. Option 6 removes the BRT from the upper deck; locating it on the lower deck in a similar way to CRT in Option 5. This enables Option 6 to have a narrower overall bridge than Options 4 and 5. Thus, the combination of fewer columns, a shallower profile, and a narrower bridge identify Option 6 as having the least adverse visual effects.

Visual effects can be considered a differentiator in the dual-level options

Screening Criteria	Option 4	Option 5	Option 6
Change in Visual Impact	• 68 piers of 2 columns • Higher bridge profile • Deeper deck structure.	• 33 piers of 2 columns • Higher bridge profile • Deeper deck structure but less than Option 4	• 33 piers of 2 columns • Higher bridge profile • Deeper deck structure but less than Option 4
Reaction to Visual Impact	• Adverse visual reaction from viewers of existing landings • Improved views for some, e.g., boaters and some close-in resident viewers • Deeper CRT deck in center more intrusive.	• Adverse visual reaction from viewers of existing landings • Improved views for some, e.g., boaters and some close-in resident viewers • Deeper CRT deck less intrusive than Option 4	• Adverse visual reaction from viewers of existing landings • Improved views for some, e.g., boaters and some close-in resident viewers • Deeper CRT deck less intrusive than Option 4

Table 4.7 - Visual Comparison of Dual Level Options

4.6.9 Community Noise

As described for the single-level options, the dual-level bridge options are not expected to significantly impact either traffic flows or transit service plans. Thus traffic flows and transit movements are not considered differentiators in terms of potential to impact community noise levels.

Bridge construction activity, near the landings, with its potential for causing community noise impacts, has been identified as a differentiating element for making comparisons among the options. Since pile driving is likely to be a major noise source during bridge construction, the number of piles to be driven for a particular option has been selected as the specific basis for comparing options (Table 4.8). With regard to the dual -level options, Options 5 and 6 have significantly fewer (33%) piles than Option 4. Construction of Options 5 and 6 is also expected to take 1½ year less than Option 4. Thus, among the options, Options 5 and 6 appear to have relatively lower potential to impact community noise levels.

Community noise is a differentiator among the dual-level options adverse to Option 4.

Deferring construction of the CRT for the dual-level options should have no noticeable effect on community noise levels.

Screening Criteria	Option 4	Option 5	Option 6
Community Noise Impacts (Total no. of piles)	2043	1364	1364

Table 4.8 - Community Noise Comparison of Bridge Options

4.6.10 Summary of Environmental Criteria

For the dual level options, notable differences adverse to Option 4 can be identified with respect to in-river impacts, particularly hydro-acoustic impacts from pile driving as well as river shading and impervious surface (Table 4.9). The lesser extent of dredging required for Option 4 results in lower levels of suspended sediments and reduced temporary loss of habitat. The same significant difference in piles driven also results in significantly adverse community noise impacts for Option 4. Finally, the greater visual bulk and larger number of columns, result in adverse historic and visual impacts for Option 4 compared to the other dual-level options.

Options 5 and 6, while not identical, generally have similar impacts to the evaluated resources while Option 4 would be expected to have greater impacts than either of the other two.

Dual Level			
Screening Criteria	Option 4	Option 5	Option 6
Land Use and Transit Oriented Development	ND	ND	ND
Displacements and Acquisitions	ND	ND	ND
Historic Resources	X	-	-
Archaeological Resources	ND	ND	ND
Parkland/4f	ND	ND	ND
Hudson River Ecosystems and Water Resources	X	-	-
Avifauna	ND	ND	ND
Visuals	X	-	-
Community Noise	X	-	-

ND – Not a differentiator X – Significant adverse differentiator

Table 4.9 - Comparison of Environmental Criteria for the Dual Level Options

4.7 Cost Evaluation

Cost
Capital Cost (cable stayed bridge)
Operating and Maintenance Cost
Life Cycle Costs

4.7.1 Capital Cost with Standard CRT Loading

This Sub-Section presents details of the Capital Cost for the Initial and Final Build of the dual-level options. The geographical limits of the work included in the cost estimate are the western end of Interchange 10 in Rockland County and the eastern edge of Interchange 9 in Westchester County and includes all construction works for the Replacement TZB and the landings.

4.7.2 Methodology

Details of the estimating methodology have been described in sub-chapter 3.6.2. The key assumptions and exclusions are repeated here.

Key Assumptions

- Cost estimates are based on the drawings included in Appendix A
- The cost of the main span structure included in this estimate is based on the total surface area of the deck and unit cost
- Main Spans are assume to be of cable stayed type only for the purposes of this estimate
- Construction cost escalation at 4.5% per year has been included to show costs in the year 2012. Escalation is factored on the total cost
- General contractor's mobilization, overhead, profit, bonding and insurance are estimated as 32%
- Soft cost and contingency are estimated at 30%

Key Exclusions (as they are the same for all single-level options)

- Existing bridge demolition
- Ship collision protection
- Roadway features like lighting, signage etc..
- Track work, signaling, third rail.
- Maintenance and operation cost

4.7.3 Dual Level Capital Costs

Table 4.10 summarizes the capital costs for the dual-level options. For each option, the table identifies total Initial Build costs and allocates the CRT Accommodation share relative to a nominal two-structure Highway/BRT crossing. Though mid-point of Initial Build construction is estimated to be 2015, Initial Build costs are developed in 2012 dollars for consistency with previous cost estimates. Final Build costs for the CRT are also identified and are in 2027 dollars, assuming the midpoint of CRT completion is 12 years following the midpoint of the Initial Build.

Overall, the total Initial Build costs for the dual-level options range from $7.27 to $7.60 billion in 2012 dollars. Initial Build costs are lowest for Option 4. The Initial Build costs of Option 6, the next most expensive option, are 2.6% higher than the Initial Build costs of Option 4, while those of Option 5, are less than 4.5% higher than Option 4. Given contingency levels (30%) included in the costs, the dual-level options are very similar in their initial cost.

Total cost represents the sum of expenditures to construct the Initial Build elements (in 2012 dollars) and Final Build elements (in 2027 dollars). Total costs range from $8.41 billion for Option 5 to $9.02 billion for Option 4, with Option 6 almost exactly in the middle at $8.85 billion. Again, the variation in cost between the lowest and highest cost options (5 vs. 4) is only 7%; and between Option 5 and Option 6, only 5%.

Costs to construct the Initial Build versions of the dual-level are not a differentiator. Total costs for an Initial Build and subsequent Final Build are a slight differentiator in favor of Option 5.

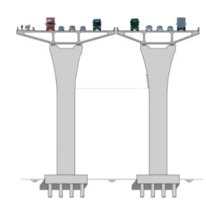
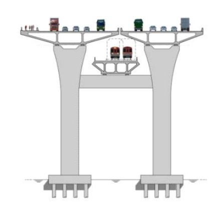
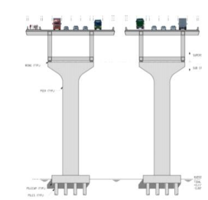
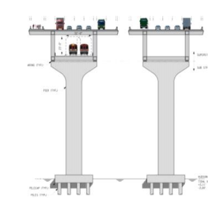
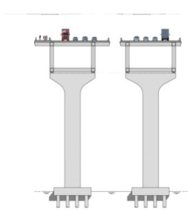
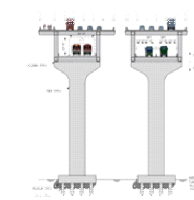
Cost Item	Option 4				Option 5				Option 6			
	Initial Build (2012 $)		CRT (2027 $)	Total	Initial Build (2012 $)		CRT (2027 $)	Total	Initial Build (2012 $)		CRT (2027 $)	Total
	Total Initial Build	CRT Accomodation			Total Initial Build	CRT Accomodation			Total Initial Build	CRT Accomodation		
Approach Structure Cost	$1,956	$397	$612	$2,567	$2,188	$629	$251	$2,439	$2,157	$598	$351	$2,508
Main Span Cost	$869	$170	$74	$943	$790	$91	$44	$834	$721	$22	$62	$783
Landing Cost (Rockland)	$226	$130	$66	$292	$222	$126	$66	$289	$267	$171	$208	$475
Landing Cost (Westchester)	$148	$18	$0	$148	$148	$18	$0	$148	$141	$11	$0	$141
Dredging & Armoring Cost	$58	$0	$33	$91	$58	$0	$0	$58	$58	$0	$0	$58
Sub Total - Base Cost	**$3,257**	**$715**	**$784**	**$4,042**	**$3,407**	**$864**	**$362**	**$3,769**	**$3,344**	**$801**	**$621**	**$3,965**
Contingency (30%)	$977	$214	$235	$1,212	$1,022	$259	$109	$1,131	$1,003	$240	$186	$1,189
General Conditions, Insurance, Overlead and Profit (32%)	$1,355	$297	$326	$1,681	$1,417	$359	$151	$1,568	$1,391	$333	$258	$1,649
Soft Costs (30%)	$1,677	$368	$404	$2,081	$1,754	$445	$186	$1,940	$1,721	$413	$320	$2,041
Total Cost	**$7,266**	**$1,594**	**$1,750**	**$9,016**	**$7,599**	**$1,927**	**$808**	**$8,407**	**$7,459**	**$1,788**	**$1,385**	**$8,845**
Bridge Cross Section												
Notes: **1. Landing costs per elements depicted in plans (all options).** **2. Rockland CRT Portal constructed in initial build**	1. CRT Accommodation compared against Single-Level Option 2 - Highway Only				1. CRT Accommodation compared against Single-Level Option 2 - Highway Only				1. CRT Accommodation compared against Single-Level Option 2 - Highway Only			

Table 4.10 - Capital Costs for Dual Level Options

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5 Conclusions

This chapter brings together the results of the evaluations and independently compares the single and dual-level options. This comparison has led to a recommendation of Option 3 for the single-level RTZB option and Option 5 for the dual-level RTZB option. The remaining options (1, 2, 4 and 6) fall significantly short of the selected options and have been eliminated from further consideration.

This chapter begins with a brief review of the key similarities and differences within the single-level and the dual-level options. It then describes the significance of the differences and how they lead to the selection of the preferred options.

5.1 Single Level Option Conclusions

Three single-level options resulted from the BODR and are depicted in Figure 1.5. Option 3 was modified prior to beginning this report:

1. **CRT in the center with three parallel Approach Structures** – Two single-level Highway BRT (HOV/HOT or Busway) structures with a third Commuter Rail Transit (CRT) structure in the center
2. **CRT on the south with three parallel Approach Structures** – Two single-level Highway BRT (HOV/HOT or Busway) structures with a third CRT structure to the south
3. **CRT in the center with two parallel Approach Structures** – Two adjacent single-level directional Highway, BRT (HOV/HOT or Busway) structures with a separate CRT deck located in the center and supported by the 2-column highway piers

Key Similarities

Casual observation of the three single-level options quickly confirms that all three have identical Highway/BRT decks. The north structures all include a 16-foot wide SUP. The CRT deck is same for all three and includes a 12-foot wide maintenance way.

All three exhibit the same profile through the landings, over the river and across the shipping channel. All have the same approach span length, nominally 230 feet. All can employ either a cable-stayed Main Span, or an arch Main Span of the same length and offset from the shipping channel.

All employ a pile based foundation system with pile caps and columns supporting deck elements. All would be constructed similarly with the substructure elements of each pier constructed concurrently, the north deck tied in to the landings first, the traffic transferred there to, the TZB demolished and the south deck completed into the landings.

All options would be designed with specific materials and details (including limited joints and contained drainage) to ensure 100-150 years before major maintenance would be required.

All provide the ability to stage the construction of the CRT, though there are vast differences in what that implies. All require an initial round of dredging of similar extent.

At the Rockland landing, all three include Initial Build construction of the portal and start of tunnel structure for CRT. The reconstruction of Interchange 10and South Broadway Bridge are expected and similar for all options. Provision of a Maintenance Accessway and an SUP connection along the north side of the Thruway are common to all three options.

At the Westchester landing, the CRT descends into the escarpment at a constant rate. All three options provide a bridge station connector (BSC) between the Highway/BRT decks from the BRT HOV/HOT lane to the proposed BRT station north of the Thruway. The area allocated for this station is similar for the three options as is the layout of the Toll Plaza, the highway-speed E-ZPass lanes, the reconstruction of the South Broadway Bridge and the flyover ramps from the HOV/HOT lanes to Interchange 9.

All options support both the Short and Long Tunnel options for the Hudson Line Connector. Though they have been designed and costed for a CRT Maintenance Train loading, all options are equally capable of being designed to accommodate a full Cooper E80 loading.

Key Differences

In Options 1 and 3, CRT is located between the highway/BRT decks, while Option 2 locates it south of the highway/BRT decks. Option 3 also uses 2 lines of columns instead of 3 to support the same superstructure. These two key differences lead to a number of other significant differences between the single-level options.

Phasing the construction of CRT takes a very different course during the Initial Build for the three options. Because of the risks and difficulties in driving 150-foot piles between completed highway decks, Option 1 must pre-construct the entire CRT substructure up front. Option 2 can do likewise and maintain a small separation (15 feet) between CRT and the south highway/BRT deck (minimum dredge version), or phase all CRT construction and increase separation (100 feet) to minimize risks to the already built structures (minimum CRT version). In either case, Option 2 would require an additional round of dredging, at minimum, to construct the phased CRT Main Span. Option 3 would require stronger highway/BRT deck columns and foundations adequate for the final form.

Engineering

1. The heavy loads of CRT would be centrally located for Options 1 and 3, leading to a **symmetrical and unified Main Span**. Option 2 would require an independent CRT Main Span structure.
2. The reduced level of effort for Option 3 results in a **6 month schedule reduction** of the 5 ½ year Initial Build schedule for Options 1 and 2.
3. While **emergency turnarounds on the RTZB** can be provided for all three options and maintenance turnarounds will be provided at both ends of the bridge, those of Option 2 would **not need to cross the CRT tracks** (requiring temporary suspension of CRT service), and thus would be more available for Thruway personnel, NYSP and first responder use. As Metro-North has indicated that suspension of CRT service can be accommodated during major emergencies, the significance of this differentiator is diminished.
4. The 15-foot separation of the highway/BRT decks from the CRT deck in Options 1 and 2 (100-foot separation in Option 2 if CRT is fully phased), would require bridging at regular intervals to provide walk-in access for emergency responders to a major CRT event (i.e., fire, derailment, etc.). As the CRT is continuously adjacent to both highway/BRT decks in Option 3, **more frequent and direct emergency response access to the CRT** is possible.
5. Access to **Main Span cables for inspection and repair has been identified as an easier** undertaking for Options 1 and 3. Option 2 would likely require closure of one CRT track to effectively and safely undertake inspections and repairs.
6. The central location of CRT in Options 1 and 3 is anticipated to result in **fewer occasions for suspension of CRT service** and reduced measures to ensure Main Span stability **during sustained high speed wind events.**

Environmental.

7. At the Rockland landing, the narrower width of Option 3, and the ability of Option 2 (minimum dredging) to connect its CRT maintenance road to River Road before reaching shore, result in **less acquisition and fewer displacements** than Option 1, which is the widest of the single-level options.
8. Option 3 has been identified as requiring **fewer displacements of historic architectural resources**.
9. Options 1 and 3 have the **least potential to affect archaeological resources**, followed by Option 2 (minimum dredge). Option 2 (minimum CRT) has the greatest potential to affect archaeological resources.

10. Option 3 has substantially fewer columns in the river (112) than Options 1 and 2 (168) While this reduces its permanent loss of habitat (not a significant differentiator), Options 1 and 2 **provide more new in-river habitat** (6.4 to 6.6 acres along the faces of its pile caps) than Option 3 (4.6 acres).
11. With **11-13% fewer piles** than for Options 1 and 2, Option 3 provides for **a significant reduction in the amount of underwater acoustic impacts to aquatic resources** during pile driving.
12. During the Final Build, CRT segments for all three options would be assembled using gantry methods. For Options 1 and 3, segment delivery would be from reconfigured adjoining highway lanes. If the substructure for Option 2 is pre-constructed (minimum dredge), segment delivery would also be from adjoining highway lanes; however, Rockland shore access, and thus dredging, will still be required to construct the CRT Main Span. If CRT in Option 2 is fully phased (minimum CRT), all construction delivery would be from the water, requiring a full second dredge. Option1 and Option 3 would **not require the second round of dredging** and thus have **reduced levels of suspended sediment loading** compared to either version of Option 2 (minimum dredge or minimum CRT).
13. The smaller dredging footprint of Option 3 also **reduces the extent of temporary loss of habitat.**
14. The 6 month **shorter construction duration** of Option 3 **reduces the level of construction impacts** upon the surrounding communities and motoring public.
15. Evaluation of the visual effect of the three single-level options identifies the **greater visual transparency** of the 2-column support of Option 3 would be more favorably received than the 3-column substructure of Options 1 and 2.
16. Tied both to the amount of pile driving and the duration of construction , **construction noise affecting the community would be substantially less** for Option 3.

Cost

17. The pre-constructed columns of Options 1 and Option 2 (minimum dredge) will remain unused until the CRT is completed. Between Initial Build and Final Build, Option 2 (minimum CRT) and Option 3 present le**ss unused infrastructure** than Option 1 and Option 2 (minimum dredge).
18. With CRT in the center for Options 1 and 3, the Main Span would be supported by 8 towers. The separate CRT Main Span structure required for Option 2, would enable a 6-tower Highway/BRT Main Span; however, the 4 towers required for the CRT Main Span results in Options 1 and 3 **requiring fewer Main Span towers**. The reduction in towers has consequential effects on maintenance, cost, schedule, number of piles and thus in-river impacts.
19. To complete the CRT, Option 3 will have similar costs (in 2025 dollars) as Option 1 ($1.93b vs. $1.85b) and **substantially lower costs to complete CRT** than Option 2, whether constructed with minimum dredging undertaken ($3.14b) or minimum CRT infrastructure initially constructed ($4.15b).
20. Options 1 and 3 require **substantially less work to complete the CRT elements of the Main Span** during Final Build than Option 2. Options 1 and 3 would only require infill transverse beams between the Main Span structures and placement of CRT deck, which could be accomplished from the adjoining highway/BRT lanes. Option 2 would require a full re-mobilization, including dredging, in-water pile driving, support facilities and all trades necessary to construct the remaining CRT foundations, and the entire CRT Main Span.
21. The Initial Build costs (in 2012 dollars for a 2015 midpoint of construction) for Options 1, 2 (minimum dredge) and 3 are similar at $6.5 to $6.7 billion. Option 2 (minimum CRT) has a 10% **lower initial cost** at $6.0 billion. This option, however, does have the greatest total cost.
22. The schedule reduction and the reduced material quantities result in an Option 3 phased construction **Total Cost savings** of $1.26b over Option 1 and $1.75b over Option 2.

Single Level Summary and Conclusion

Overall, there are major differences between Option 3 versus Options 1 and 2 with Option 3 the clear preference because of the reduction by 33% of the number of piers in the river, leading to reduction in construction activities, construction duration, initial and final construction costs and the significant reduction in impacts to the Hudson River and aquatic resources. Option 3 is recommended for further evaluation as the Single Level Option in the *DEIS*.

	Issue	Criteria	1	2 - Min CRT	2 - Min Dredge	3
	Engineering					
1	Symmetrical and unified Main Span	Structural Integrity	✓			✓
2	Reduced Schedule	Construction Impacts	✓			✓
3	Non-CRT crossing Emergency Turnarounds	Emergency Response		✓	✓	
4	Better Emergency Response access to CRT	Emergency Response				✓
5	Easier Main Span Cable inspection and repair	Operations and Risk	✓			✓
6	Fewer wind caused CRT suspensions	Operations and Risk	✓			✓
	Environmental					
7	Fewer acquisitions and displacements	Displacements and Acquisitions			✓	✓
8	Fewer displacements of Historic Resources	Historic Resources				✓
9	Least potential to affect archaeological resources	Archaeological Resources	✓			✓
10	Greater in-river habitat	Ecosystems and Water Resources				✓
11	Reduced underwater acoustic impacts	Ecosystems and Water Resources				✓
12	Reduced suspended sediment loading	Ecosystems and Water Resources	✓			✓
13	Reduced temporary loss of habitat	Ecosystems and Water Resources				✓
14	Reduced construction duration	Ecosystems and Water Resources				
15	Greater visual transparency	Visual				✓
16	Reduced construction noise	Community Noise				✓
	Cost					
17	Less Unused Initial infrastructure	Capital Cost		✓		✓
18	Fewer Main Span Towers	Capital Cost	✓			✓
19	Lower Cost to complete CRT	Capital Cost	✓			✓
20	Less effort to complete CRT elements of Main Span	Capital Cost	✓			✓
21	Lower Initial Cost	Capital Cost		✓		
22	Lower Total Cost	Capital Cost				✓

Table **5.1 - Summary of Single Level Differences**

5.2 Dual Level Option Conclusions

Three Dual Level Options (numbered 4 - 6) resulted from the BODR and are shown in Figure 5.

4. **Stacked -** A hybrid stacked single structure with two Highway BRT (HOV/HOT or Busway) decks above a centrally located CRT deck. Supporting structure is either concrete or steel girders and is approximately 15 feet deep.
5. **CRT on lower level of north structure –** Two dual-level Highway BRT (HOV/HOT or Busway) structures with CRT in the north bay. Supporting structure is a steel truss.
6. **All transit (BRT and CRT) on lower level –** Two dual-level structures with only Highway above and CRT in the north bay and BRT (Busway) in the south bay. Supporting Structure is a steel truss.

These options differ physically only in (1) the type of substructure (H-frame or pier columns), (2) the type of deck structure (truss or girder) and (3) the location of BRT within the bridge cross section (either on the upper or lower level). Consideration of these physical differences led to the recommended option.

Key Similarities

The highway/BRT decks of Option 4 provide the same lane arrangement as the decks of Option 5. The arrangement of 2 CRT tracks and a 12-foot maintenance way is the same for the three dual-level alternatives. All three provide for a 16-foot SUP along the north structure.

The two truss based options, 5 and 6, have the same profile through the landings, over the river and across the shipping channel. These two options have the same approach span length, nominally 430 feet. All three dual-level options can employ either a cable-stayed Main Span, or an arch Main Span of the same length and offset from the shipping channel.

All employ a pile based foundation system with pile caps and columns supporting deck elements. The two truss based options, 5 and 6, would be constructed similarly with the substructure elements of each pier constructed concurrently, the north deck tied in to the landings first, the traffic transferred there to, the TZB demolished and the south deck completed into the landings.

All options would be designed with specific materials and details (including limited joints and contained drainage) to ensure 100-150 years before major maintenance would be required.

All provide the ability to stage the construction of the CRT, though there are vast differences in what that implies. All require an initial round of dredging with similar quantities required for Options 5 and 6.

At the Rockland landing, all three include Initial Build construction of the portal and start of tunnel structure for CRT. The reconstruction of Interchange 10 and South Broadway Bridge are expected and similar for all options. Provision of a Maintenance Accessway and an SUP connection along the north side of the Thruway are common to all three options.

At the Westchester landing, the CRT descends into the escarpment at a constant rate. All three options provide a bridge station connector (BSC) between the Highway/BRT decks from the BRT HOV/HOT lane to the proposed BRT station north of the Thruway. The area allocated for this station is similar for the three options as is the layout of the Toll Plaza, the highway-speed E-ZPass lanes, the reconstruction of the South Broadway Bridge and the flyover ramps from the HOV/HOT lanes to Interchange 9.

All options support both the Short and Long Tunnel options for the Hudson Line Connector. Though they have been designed and costed for a CRT loading, all options are equally capable of being designed to accommodate a full Cooper E80 loading.

For all dual-level options, temporary suspension of CRT service on one or both tracks would be required to facilitate inspection of the bridge structure above the CRT.

Emergency access to the CRT for all dual-level options would be via stairways located at intervals along the full length of the crossing.

Key differences

Simple inspection identifies that Option 4 is quite different than Options 5 and 6, which in structural form are practically identical. Option 4 is more akin to single-level Option 3, employing a concrete H-frame pier arrangement with a transverse box girder of either concrete or steel. The superstructure consists of three closed cell segmental concrete frames integral with their decks, though the configurations could also have utilized steel. Over the Main Span, Option 4 integrates the three decks into a single combined lateral and longitudinal 2-way truss held up at its edges by stays or hangers.

Dual Level Options 5 and 6 have similar structural form. For the Approach, the sub-structure consists of single piers and the super-structure is a longitudinal steel truss. Over the Main Span, the truss continues and is held up by stays or hangers. The principal differences between Options 5 and 6 are the smaller highway decks of the latter as BRT is relocated to the lower bay of the south structure.

In Option 5, BRT is located on the upper level adjacent to the general purpose highway lanes. In this location, BRT could operate either as a dedicated Busway or in HOV/HOT lanes. In Option 6, BRT operates as a Busway on the lower level of the southern structure and is separated from the general purpose lanes on the upper level.

There are significant differences in the construction of Option 4 versus the construction of Options 5 and 6. While all three options require the concurrent construction of both pier columns, the construction of their superstructure would use very different methods. The segmental concrete CRT and Highway/BRT decks of Option 4 would likely be constructed using gantry methods to assemble a span followed by post-tensioning. The assembly of the CRT deck would precede that of the highway decks by several spans. By contrast, the truss superstructure of Options 5 and 6 would likely be barged to the site as large full cross section units (side trusses and top and bottom bracing). Using a specialized barge crane, 50-foot units would be placed atop completed columns and fixed in position. The remaining central portion of the span would then be barged in and winched into position, then secured and welded to form a continuous span. Following this, prefabricated concrete deck elements would be trucked to the site and placed atop the structural box.

While the methods of Option 4 are different from those of Options 5 and 6, both involve the offsite prefabrication of elements and delivery by barges. Differences in equipment – specialized barge crane versus 3 purpose-built gantries and associated schedules and costs are negligible.

If the construction of CRT is phased, two avenues are available to Option 4. The one method would phase construction of the entire CRT approach structure deck and the transverse beams as well. During final build the transverse beams would be formed and cast in place, or installed as prefabricated units and post-tensioned. The CRT deck would be constructed using an under-slung articulated gantry with segments delivered from the completed CRT deck. The other approach recognizes the difficulties and impacts of the first method and constructs the entire CRT approach structure deck during the Initial Build as described in the previous paragraph using gantry methods and just ahead of the highway decks. The only CRT items phased in this case would be the installation of the track and other train systems. Thus, phasing the construction of CRT in Option 4 is either: costly and difficult, or obliges the construction of virtually the entire CRT system, short of laying the track and installing the signals.

By contrast, phasing CRT construction in Options 5 and 6 simply involves phasing the installation of the CRT track bed along with the track and systems that would be installed thereupon. For Option 6, BRT likewise can also be phased, with installation of the Busway roadbed similarly phased. All this work can occur quickly and from the bridge itself with no in-river work required. Some accommodation of CRT (and BRT) is required as the substructure and superstructure have to be sized to meet the eventual loads added during the Final Build. The costs phased would be $808 million for CRT in Option 5 and $1.385 billion for CRT and BRT in Option 6.

Engineering

2. The over-under arrangement of Option 4 makes it impossible to include central pylons or arches for the Main Span, thus the approach cross section must transition to a single composite structure supported by

four pylons or arches outside of the decks. This would require exceptionally strengthened pylons or arches to support the massive composite structural deck. Options 5 and 6 avoid this level of strengthening and complexity by employing six pylons or arches to support **simple Main Span structures** over two adjacent spans.

3. The reduced number of piles and piers and the simpler erection methods of the truss structures **reduce the Initial Build schedule** to construct Options 5 and 6 by 1½ years compared to Option 4.
4. A significant difference between Options 4 and 5 and Option 6 is the overall width of the bridge structures. The width of the north span of Option 6 is only 94 feet. During construction, when all traffic is diverted to the north structure, this limited width would be able to only support a 7-lane operation employing a movable barrier, if standard 12-foot lanes are used. If substandard 11-foot lanes are used, an 8-lane fixed barrier operation could be employed. At 110 feet across, the north structures of Options 4 and 5 **support a full 12-foot wide, 8-lane fixed barrier operation during the temporary condition**.
5. The box girder form of the Option 4 highway decks is limited in its ability to effect a full deck replacement, potentially limiting the life span of the superstructure. Options 5 and 6 support the **ability to fully replace the roadway deck.**
6. In Option 4, because of the close proximity of the highway deck structures, access for standard inspection equipment would be difficult. As an under-bridge inspection unit (UBIU) would not be able to reach under the full width of the bridge, special inspection gantries would need to be utilized. In Options 5 and 6, **easier access for inspection** would be provided on the lower level without any interruption of traffic or temporary lane or shoulder closures on the highway above, but may require the temporary suspension of CRT.
7. All the dual-level options have CRT on the lower level with the same potential accidental and intention risks associated with fire, impact and explosion. Options 4 and 5 have **reduced risks**, compared to Option 6**,** associated with similar (though possibly much more impactful) events in the BRT lanes on the lower level due to the potential to access these lanes by large vehicles. These risks, particularly those associated with Intentional Events are considered significant with the potential for major damage.
8. The location of CRT within the structural trusses of Options 5 and 6 may, compared to Option 4, **result in fewer occasions for suspension of CRT service due to sustained high wind events**. The over-under arrangement of Option 4 may result in eddies and increased wind forces upon the CRT.
9. The location of CRT within the structural trusses of Options 5 and 6 may also, compared to Option 4, **reduce the risk of CRT leaving the structure during an extreme derailment**.
10. Option 4 and 5 **maximize the flexibility of highway operations in the event of vehicle accidents.** Should a significant accident occur, traffic would be diverted around the incident if possible. The larger width of Option 5 due to its inclusion of the BRT lane on its upper level would provide greater space for traffic to be diverted than would be available for Option 6. Diversion on to the Busway below would not be desirable as the access and egress points to the Busway at each landing could not accommodate major traffic volumes or would channel traffic through the possible BRT station at the Tarrytown landing.

Transportation

11. Options 4 and 5 **maximize the operational flexibility of the vehicular transport system in the corridor** as it accommodates BRT in either a Busway or in HOV/HOT lanes, and places these lanes together with the general purpose highway lanes. Having these lanes together provides the most flexibility, whether managing major incidents or anticipating long term changes in mobility, to adapt the wider available deck surface to necessary demands.
12. Likewise Options 4 and 5 with their larger decks, provide a **larger degree of reserve capacity** that can be practically employed than can be developed with the busway system and narrower decks of Option 6.
13. Options 4 and 5 support the both the BRT HOV/HOT and the Busway alternatives. Option 6 does not support the BRT HOV/HOT Alternative.

Environmental

14. Based upon indirect visual impacts, Option 6, closely followed by Option 5 would have the **least potential to adversely impact historic architectural resources**.
15. With BRT on the lower level and thus narrower decks, Option 6 **results in less shading of the river** (16-19%) than Options 4 and 5.
16. Similarly, Option 6 results in less impervious surface (16-19%) and thus **reduced stormwater management requirements** than Options 4 and 5.
17. The greater number (112) of in-river piers of Option 4 results **in a greater quantity of vertical in-river habitat** (38%) upon the faces of the pier caps, compared with the fewer number (64)of piers of Options 5 and 6.
18. Option 4 with its closer pier spacing, and heavier dead load requires 49% more piles than Options 5 & 6. As a result, Opti**ons 5 & 6 have** substantially **reduced underwater acoustic impacts**, both in quantity and duration.
19. The construction techniques to erect Option 4 require a smaller dredged access channel and thus result in **lower levels of suspended sediment loading** compared to Option 5 (13%) and Option 6 (7%).
20. The smaller dredged access channel of Option 4 also results in similar reduction in temporary loss of habitat compared to Option 5 (13%) and Option 6 (7%).
21. The 12 month shorter construction duration of Options 5 and 6 **reduces the level of construction impacts** upon the surrounding communities and motoring public.
22. Evaluation of the visual effect of the three dual-level options identifies the fewer number of piers and **reduced visual presence of the superstructure** of Options 5 and 6 would be more favorably received than the more massive and deeper superstructure of Option 4.
23. With significantly less pile driving and shorter construction schedule by a year, **construction noise affecting the surrounding communities would be substantially less** for Options 5 and 6.

Cost

24. The Initial Build Capital cost (in 2012 dollars for a 2015 midpoint of construction) for the RTZB for Dual Level Options 4, 5 and 6 are very similar at $7.27, $7.60, and $7.46 billion, respectively. These costs are reported in 2012 dollars and include contingency, escalation and soft costs. The Final Build Capital costs to add the CRT (and for Option 6 the BRT busway) are $1.750 billion, $808 million, and $1.385 billion for the respective Dual Level Options. These costs are in 2027 dollars. Summing these, while recognizing the difference in years spent, leads to a Total Capital cost of $9.02, $8.41, and $ 8.85 billion for Dual Level Options 4, 5 and 6. The **lower Total Capital cost** for Option 5 is principally due to the lower cost to complete the Final Build transit elements, consisting only of CRT.

	Issue	Criteria	4	5	6
	Engineering				
1	Simple Main Span Structures	Structural Integrity		✓	✓
2	Reduced Initial Build Schedule	Construction Impacts		✓	✓
3	8 12-foot lanes on North Structure during construction	Construction Impacts		✓	✓
4	Better ability to replace Highway deck	Operations and Risk		✓	✓
5	Easier access for inspection	Operations and Risk	✓	✓	✓
6	Reduced risks from intentional events	Operations and Risk	✓	✓	
7	Fewer wind caused CRT suspensions	Operations and Risk		✓	✓
8	Reduced risk of CRT leaving the structure	Operations and Risk		✓	✓
9	Maximum flexibility of highway operations during vehicle accidents	Operations and Risk	✓	✓	
	Transportation				
10	Maximum system flexibility	Reserve capacity	✓	✓	
11	Larger reserve capacity	Reserve capacity	✓	✓	
12	Supports both the BRT HOV/HOT alternative and the BRT Buslane alternative	Transportation System Integration	✓	✓	
	Environmental				
13	Least potential indirect visual impact to Historic Resources	Historic Resources		✓	✓
14	Less shading of the river	Ecosystems and Water Resources			✓
15	Reduced stormwater management requirements	Ecosystems and Water Resources			✓
16	Greater in-river habitat	Ecosystems and Water Resources	✓		
17	Reduced underwater acoustic impacts	Ecosystems and Water Resources		✓	✓
18	Reduced suspended sediment loading	Ecosystems and Water Resources	✓		
19	Reduced temporary loss of habitat	Ecosystems and Water Resources	✓		
20	Reduced construction duration	Ecosystems and Water Resources		✓	✓
21	Reduced visual presence	Visual		✓	✓
22	Reduced construction noise	Community Noise		✓	✓
	Cost				
23	Lower Total Cost	Capital Cost		✓	

Table 5.2 - Summary of Dual Level Differences

Dual Level Summary and Conclusion

Overall, there are major differences between Option 4 versus Options 5 and 6. Options 5 and 6 are preferred because of the lesser construction activities in the Hudson River, construction duration, and construction cost associated with the lesser number of piers required. In addition, Options 5 and 6 are preferred as they provide better inspection access, longer potential deck life span and lesser total structural depth. Options 5 and 6 also provide for easier phasing of constructed elements. Though Option 4 has lesser dredging requirements, this advantage is overwhelmed by the other advantages offered by Options 5 and 6.

Overall, Option 5 is preferred over Option 6 because of its inherent transport flexibility to both meet future needs and to facilitate emergency response and recovery during accidents and major incidents. Option 5 is also preferred because of the reduction relative to Option 6 of both potential consequences and probability of occurrence associated with intentional events enabled by preventing vehicular access to a lower bay (BRT). Full Build Costs for Option 5 are also significantly lower by over $400 million. Recognizing that Option 4 is decidedly less desirable that Options 5 or 6 and that Option 5 is significantly preferable to Option 6, Option 5 is recommended for further evaluation in the *DEIS*.

5.3 Selected RTZB Alternatives for Replacement of the Tappan Zee Bridge

This report concludes and documents Step 2 of the RTZB development and selection process with the selection and recommendation of two of the six *BODR* Options to serve as RTZB Alternatives for evaluation in the *DEIS* to replace the TZB. The two alternatives chosen have survived a rigorous screening process that has first considered and winnowed a broad array of options using engineering based criteria developed from the Project's Purpose and Need; a process documented in the *BODR*. The six options that emerged from the *BODR* have been further developed and investigated and evaluated against the Project's broader set of Engineering, Transportation, Environmental and Cost criteria, all of which are also developed in the context of the Project's Purpose and Need and broader Goals and Objectives. Review of the differences within the single-level and dual-level options (Table 5.1 and Table 5.2), indicates the broad superiority of the selected options against the next best choices.

The options selected: Single-level CRT Center Two Structures (Option 3), and Dual-level CRT North Two Structures (Option 5) represent the best arrangement of the two structural types (segmental concrete and steel truss) most suited for the 3-mile crossing of the Hudson River. Both options provide for the ready and simple phasing of the CRT elements without the need for significant in-river work or supplemental dredging.

The two-column piers of both options reduce the visual presence of the Tappan Zee Bridge within the natural environment of the Hudson River. The profile of the bridge and form of the structure, while admittedly man-made, will still provide a simple and graceful form that will be less visually intrusive than the existing TZB.

In concordance with Step 3 of the bridge development and selection process, identified in Chapter 1, Options 3 and 5 will be the RTZB Alternatives to be evaluated in the *DEIS*.

Figure 5.1 - RTZB Alternatives to be Evaluated in the DEIS