9 Conclusion

9.1 Introduction

This final chapter presents a synthesis of the evaluation criteria leading to conclusions and recommendations. Also included is a summary of the current status of the TZB outlining its condition, limits and vulnerabilities as a reminder of the need for either rehabilitation or replacement.

9.2 Existing TZB Condition, Limits and Vulnerabilities

Extensive surveys and inspections of the existing TZB were conducted and assessments made of its condition, structural capacity and vulnerabilities. These studies concluded that the existing TZB was safe for current traffic loading, but with notable vulnerabilities that could result in the loss of the crossing for substantial periods and durability concerns that need to be addressed to ensure long term safe operation.

As a critical piece of regional infrastructure, the TZB affects the lives of millions of users, as well as the economic vitality of the whole region. Accordingly, it is held to the highest performance standards and it is required to remain safe well into the future. Based on current maintenance requirements and the assessments conducted for this report, rehabilitation or replacement of the TZB is considered essential if the TZB is to remain in operation well into the future. Particular concerns include:

Condition

- The rate of deterioration of the TZB is unusually high as a consequence of its design, the de-icing salts used on it since construction and the saltwater environment of the Hudson River
- While the NYSTA has implemented major repair contracts to maintain the TZB in a safe condition, the scale of the ongoing maintenance and repairs is escalating. The complexity and scale of the TZB, its maintenance access difficulties, the need to work around traffic and the absence of shoulders increase the cost and duration of repairs
- The design of the existing bridge includes components that have a limited life span or are the source of major ongoing repairs, these include: a thin deck, a large number of joints, open drains, open steel sections and timber piles
- The high volume of truck traffic on the TZB is detrimental to the structure and in particular the bridge deck

Limits

- The TZB does not meet the current seismic performance standards for critically important bridges. Should either the functional (1 in 500 years) or safety (1 in 2,500 years) seismic design-event occur, the extent of repair work required would likely require closure of the TZB for a substantial period (years). Based on the analysis conducted, major damage to various segments of the TZB is possible

Vulnerabilities

- Overall vulnerability is above the level that is commonly acceptable for major bridges. Vulnerabilities are associated with concrete and steel details inherent in the design of the bridge
- The TZB is vulnerable to extreme events with the potential for major damage to large sections of the bridge following deliberate actions
- The TZB is not structurally redundant. The failure of any one of many primary members may result in major damage to the TZB
- Current analysis indicates that the Main Spans have lower factors of safety against wind loads than are specified in current standards
- The vehicular accident rate on the TZB is substantially higher than the state-wide average. This is caused by many factors including lack of shoulders, high traffic volumes, narrow lane widths, sun glare, substandard drainage run-off, substandard super-elevation, steep grades, high truck volumes, driver frustration, movements of the central barrier, continuous and changing lane closures and lane changing movements at the Toll Plaza

All of the Rehabilitation Options include extensive modifications to address the conditions, limits and vulnerabilities outlined above. For the 166 Causeway spans of the TZB, the modifications are not considered reasonable, practical, or economic. As a result, all of the Rehabilitation Options include the replacement of the existing Causeway, which represents over one half of the length of the overall bridge.

9.3 Future Maintenance Requirements of the Existing TZB

Maintenance requirements of the existing bridge are becoming so extensive that, at some point in the future, the continuous maintenance of the TZB will be become so disruptive and costly as to render the crossing obsolete, affecting the vitality of the region.

Expenditure of $1 billion (2012 dollars) is required in the current decade to maintain the TZB in safe condition. In each of the last three decades, the maintenance expenditure on the TZB more than doubled when compared to the preceding decade. Without action to rehabilitate or replace the TZB, these expenditures are anticipated to increase even more quickly.

The reasons for the high maintenance cost for the TZB are many, but the primary sources include:

- The intention of the original bridge designers was to make the deck and the TZB as light as possible to avoid the need for deep foundations and their associated costs. The decks are thin and light, giving initial cost savings, but with long term durability disadvantages as they were not intended to withstand current truck loadings and volumes
- The original 200 deck joints, provided to accommodate settlement in the soft riverbed soils, have allowed water and road salts to penetrate through the deck and on to all elements of the substructure below, causing corrosion of steel and cracking and spalling of concrete
- Open edge and former central drains allowed road salts to penetrate all the components of the substructure
- The salt environment of the Hudson River penetrates the concrete of the piers causing reinforcement corrosion, cracking and spalling of concrete
- The large number of repeating, short Causeway spans means that any single defect implies 166 similar defects on the other spans. The number of components to be maintained is much higher than other long bridges because of the short spans used in the Causeway
- The absence of shoulders on the TZB and a desire to minimize traffic disruption requires much maintenance to occur at night, with associated higher costs

Overall, it is evident that the TZB was designed and built to a strict budget. While long term maintenance was undoubtedly considered during the original design, the components and details used were not conducive to long term durability.

While the increasing NYSTA efforts and substantial expenditures will preserve the TZB, they would:

- Not provide any change in transportation capacity
- Not include any improvements to reduce the high accident rate
- Not address safety concerns because of spatial limitations
- Not have any dedicated provision for transit

9.4 Option Evaluation

9.4.1 Rehabilitation Option 1

As part of the overall TZB/I-287 Environmental Review, of which this report is a part, it has been identified in the Project's Purpose and Need statement, that to improve the mobility of the I-287 Corridor, transit of some form will be necessary. It has also been identified, and documented in the Purpose and Need statement, that any modifications to the TZB must improve safety and mobility and bring the TZB into compliance with current standards (See text box). Rehabilitation Option 1 does not comply with these primary requirements and is therefore not recommended for study in the DEIS. Specific issues identified in the various Evaluation Criteria include:

- Absence of a dedicated travel way to provide reliable transit
- No significant opportunity for diversion from private vehicles to transit modes
- Largest predicted vehicle miles travelled and associated emissions
- Higher accident rates resulting from lack of shoulders, eastbound lane drop, continued use of moveable barrier, and non-standard lane widths.

Purpose and Need

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

Rehabilitation of the TZB to improve its condition, structural capacity and seismic behavior is possible, but this would require replacement of the Causeway and the extensive reconstruction of the foundations for all segments of the TZB including the removal of the Buoyant Caissons of the Main Spans and Deck Truss Spans. These caissons are a unique feature of the TZB, but their mass and structural characteristics are a major disadvantage in seismic events. Analysis demonstrated that substantial cracking would develop in the Buoyant Caissons resulting in a potential loss of buoyancy leading to major damage to the Main Spans. To ensure predictable behavior and controlled damage during a seismic event, new foundations replacing each Buoyant Foundation are necessary.

The need to replace the Buoyant Foundations and strengthen all other foundations on the TZB would result in extensive piling and pile cap construction in the Hudson River. Many of the foundations for the Rehabilitation Options are larger and more complex than those in the Replacement Options because of the need to build around the existing structure. When compared to the extent of the foundation construction required in the river for the Replacement Options, the extent and scale of the construction is similar with only small differences in the exact numbers of piles.

Though the rehabilitation efforts would bring the TZB into compliance with current requirements, substantial vulnerabilities and risks would remain with respect to structural integrity. These are primarily associated with extreme events including deliberate actions with the potential for major damage to large sections of the TZB. Performance under deliberate events would be substantially improved in the Replacement Options by the inclusion of adequate redundancy, limited access, offsets and other design features.

The estimated capital cost of Rehabilitation Option 1 is $3.4 billion (2012 dollars) with a present value maintenance cost of $1.1 billion. This capital cost is higher than the maintenance prediction of $1.0 billion for the existing TZB over the next decade, principally due to the foundation upgrades, Causeway replacement and modifications to minimize future maintenance and traffic disruption. The discounted value of maintenance costs for Rehabilitation Option 1 is $1.1 billion. This high cost is a consequence of the short life span of many of the retained components of the existing TZB. For example, repair of the existing concrete columns supporting the Deck Truss Spans would be required at regular intervals due to the historic contamination from highway de-icing salts and the marine environment. At a minimum, the sum of the capital and maintenance cost, $4.5 billion, is the least investment that will ensure the continued safe operation of the TZB well in to the future.

The capital cost for Rehabilitation Option 1 is 62% of the least expensive full replacement bridge option ($5.2 billion for Replacement Option 1). At this percentage, the *NYSDOT Bridge Manual* does not identify a preference for rehabilitation or replacement. However, the capital cost of Rehabilitation Option 1 (91 feet width) is 20% more than the cost of just one span of Replacement Option 1 (109 feet width). At this percentage, the NYSDOT Bridge Manual states a clear preference for replacement over rehabilitation as long as environmental and ROW impacts are comparable.

9.4.2 Rehabilitation Option 2

Similar to Rehabilitation Option 1, major structural modifications, strengthening and reconfiguration is required for the remaining segments of the existing TZB in Rehabilitation Option 2. These include:

- Replacement of all of the Buoyant Foundations
- Strengthening of all other existing foundations
- Pier modifications and strengthening
- Modifications and strengthening of superstructure steelwork
- Replacement of existing bearings with special isolation bearings

Across all evaluation criteria, a number of major undesirable characteristics were identified and this option was found to be infeasible. Undesirable characteristics included:

- The first, a traffic safety issue, concerns the safety of the split in the highway lanes around the existing Main Spans trusses in each direction. The presence of the split between the two outer lanes, the change in grade at the west approach to the Main Spans, the high curvature and super-elevation in the east approach and the traffic maneuvers required in the approach to the Toll Plaza, are all undesirable factors that are sufficient to create unsafe driving conditions at Interstate highway speeds.
- The second characteristic resulted from consideration of the maintenance and protection of traffic during construction. The scale of the modifications required to the edge of both sides of the existing TZB, both in the Main Spans and the Deck Truss Spans, would result in major disruption of traffic for a number of years and a significantly longer construction program than other options.
- Finally, the estimated construction cost of Rehabilitation Option 2 is the highest of all the rehabilitation options considered and has the longest construction duration (10-12 years) with associated construction impacts. This is due to the construction complexities and risks associated with the modification of every piece of steel, in all members and at all connections in the Main Spans.

Overall, the extent of the modifications required affected almost every member on the TZB. In particular, every member of the existing trusses in the Main Spans and in both the East and West Deck Truss Spans would need to be modified and strengthened while the TZB remained open to traffic. The associated construction, safety and cost risks are considered unacceptable compared to Rehabilitation Option 3 or 4. Rehabilitation Option 2 is not considered feasible and it is recommended that it not be progressed into the DEIS.

9.4.3 Rehabilitation Options 3 and 4 Compared to the Replacement Options

With the elimination of Rehabilitation Options 1 and 2, the remaining options, Rehabilitation Options 3 and 4 are directly comparable to the three Replacement Options with the same transit mode. The options, which have the exact same transport modes and hence transportation performance are:

- Rehabilitation Option 3 or Replacement Option 1 for BRT transit
- Rehabilitation Option 4 or Replacement Options 2 and 3 for CRT transit

For the equivalent modal options, there is no difference in the physical requirements at the Rockland Landing, as all options have the same footprint, and therefore, the same environmental impacts, transport implications and costs. Similarly, at the Westchester Landing, there are no notable differences among the options. Though there is

further work for all options to minimize the high level encroachment above the tennis courts at the Quay, there are no substantive differentiators between comparable modal options.

In the Hudson River, because of the modifications required to existing foundations to meet seismic requirements (as outlined in the discussion of Rehabilitation Option 1 above), the scale of construction required, as measured by the number of new piles required in the river, differs by only 5% for the comparable BRT options. The result for the comparable CRT options is similar, though Replacement Option 2, with its independent CRT bridge, would require 30% more piles. Overall, the minimum number of piles required for comparable options is similar and the scale of construction in the river is not a major differentiator among options.

The major differentiators between Rehabilitation Options 3 and 4 and the Replacement Options with comparable transit mode come from the engineering and cost criteria as follows:

- The **Life Span** of the bridge components retained in the Rehabilitation Options would be shorter than those of the Replacement Options. This is a consequence of the historical contamination that is now ingrained in many components from 50 years of aging and exposure to salts. The Replacement Options can take advantage of major improvements in materials and design leading to significantly longer component life spans and lower maintenance needs
- A lack of **Redundancy** would remain a characteristic of the TZB in the Rehabilitation Options with the TZB remaining susceptible to extreme events. In the Replacement Options, adequate redundancy would be provided and structural performance improved
- While modifications in the Rehabilitation Options have been included to ensure compliance with the **Seismic Criteria**, that compliance is based on strength rather than ductility. As such, the Rehabilitation Options are unlikely to survive an event larger than the design event. In the Replacement Options, which are designed to behave in a ductile manner, the ability to survive a seismic event larger than the design event is greatly improved
- While the scale of work is similar in all options, it is in the sequencing of construction, and in particular access to the existing TZB superstructure in the Rehabilitation Options, that results in a difference in construction duration under the **Construction Impacts** criterion. Construction duration for the Replacement Options is approximately one year shorter than that of the Rehabilitation Options
- The Rehabilitation Options would also include uniquely complex construction techniques, associated with the transfer of the bridge weight, from the existing Buoyant Foundations to new replacement foundations. The Replacement Options can be constructed using off-site prefabrication and proven rapid assembly methods
- The difference in the **Capital Cost** between rehabilitation and replacement was shown to be nominal, with differences of less than 5% for comparable options, significantly less than the contingencies incorporated in the cost estimates. As a result, capital cost is not considered a differentiator. However, based on the NYSDOT Bridge Manual, the rehabilitation costs are above the 85% threshold, at which there is a preference for replacement
- The present values of the **Maintenance Costs** differ substantially. For the two remaining Rehabilitation Options the maintenance cost range is $1.2 - $1.4 billion. The comparable range for the Replacement Options is $0.7 billion. This significant difference is a result of the longer life span and longer periods between repairs for the components in the Replacement Options
- Finally, it is noted, that 80% of the Rehabilitation Options would be new structure. The Rehabilitation Options would be so similar to full replacement, that acceptance of the construction complexities, lower performance and higher maintenance costs of the residual 20% of the Rehabilitation Options is not reasonable

9.5 Conclusions and Recommendations

Based on the evaluation of the seven Rehabilitation and Replacement Options, the following factors lead to a recommendation:

Rehabilitation Options 1 & 2 are unacceptable.

- Rehabilitation Option 1 does not comply with the Project's Purpose and Need and should therefore not be progressed into the DEIS
- Rehabilitation Option 2 has unacceptable traffic safety concerns at the Main Spans as well as disproportionate construction impacts, duration and risks. The modifications to the Deck Trusses and Main Spans are so extensive and difficult as to bring into question the feasibility of its construction and containment of costs. These concerns are considered sufficient to eliminate this option compared to Rehabilitation Options 3 and 4 and should therefore not be progressed into the DEIS

Rehabilitation Options 3 & 4 are 80% new and identical to the Replacement Options.

- All options, both Rehabilitation and Replacement, include substantial replacement of the TZB. All options include replacement of the Causeway that extends just over half way across the Hudson River. The Rehabilitation and Replacement Options differ only in whether they also replace the Deck Truss and Main Spans in the eastern half of the TZB
- As a result, Rehabilitation Options 3 and 4 are 80% the same as the comparable Replacement Options but with significantly higher maintenance requirements and vulnerabilities in the residual 20% of the existing TZB
- The potential environmental impacts of the Replacement Options are similar to those of the Rehabilitation Options
- The transportation performance of the Rehabilitation and Replacement Options with common transit modes (BRT or CRT) is the same

Repairs and improvements to Rehabilitation Options 3 & 4 are extensive, complex and risky. When completed they are still inadequate relative to the performance criteria and are inferior to new construction.

- For the Rehabilitation Options, the structural modifications, strengthening and reconfiguration required for the remaining segments of the existing TZB are complex, substantial and of similar scale to the construction associated with the Replacement Options. Modifications in the Rehabilitation Options include:
  - Replacement of all of the Buoyant Foundations
  - Strengthening of all other existing foundations
  - Pier modifications and strengthening
  - Modifications and strengthening of superstructure steelwork
  - Replacement of existing bearings with special isolation bearings
- While the overall structural condition and capacity of the TZB is improved in the Rehabilitation Options, substantial vulnerabilities and risks remain along with a lack of redundancy
- The remaining life span of many of the components of the existing TZB retained in the Rehabilitation Options would be less than that of the same components in the Replacement Options. While the life span of all options can be extended, more extensive repairs and shorter maintenance cycles would be expected in the Rehabilitation Options. It is expected that some components in the Rehabilitation Options would require major repair or replacement in 20-50 years – a period much shorter than the NYSTA operating requirement of no major component replacement for the first 100 years.

Replacement Options meet the Purpose and Need and all the Evaluation Criteria for less overall cost, and similar impacts.

- A replacement crossing would be designed and constructed in compliance with current standards for structural design and integrity
- A replacement crossing would be designed with adequate redundancy including provisions for extreme events appropriate to critical infrastructure
- A replacement crossing would be designed to survive the safety level seismic event with predictable and reliable performance
- A replacement crossing would have similar capital and lower life cycle costs than a rehabilitated crossing.

Overall, the extent of the modifications and new structure required for the Rehabilitation Options to comply with the Project's Purpose and Need and Evaluation Criteria are so substantial as to render rehabilitation impractical compared to the Replacement Options – 80% of the TZB in the Rehabilitation Options is new and is the exact same as that in the Replacement Options. The Rehabilitation Options are not reasonable – for similar environmental impacts, transport performance and capital costs as in the Rehabilitation Options, the Replacement Options have improved engineering performance, lower maintenance costs, reduced construction risk, lesser unknowns and shorter construction duration.

Based on assessment of the Rehabilitation Options through the Project's Purpose and Needs and Evaluation Criteria, rehabilitation of the Tappan Zee Bridge is neither reasonable nor prudent. Only TZB Replacement Options are recommended for inclusion in the DEIS, the next stage in the TZB/I-287 Environmental Review.