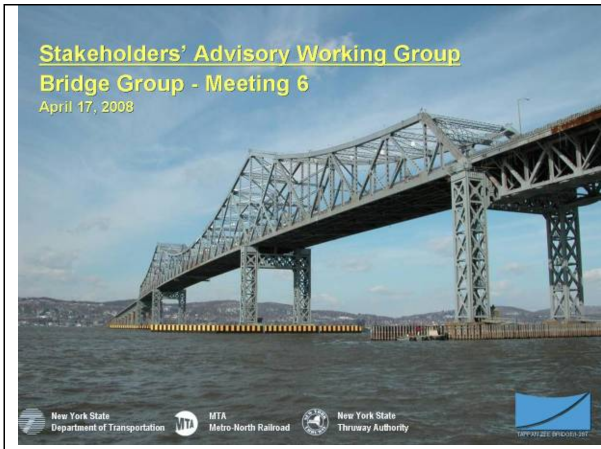
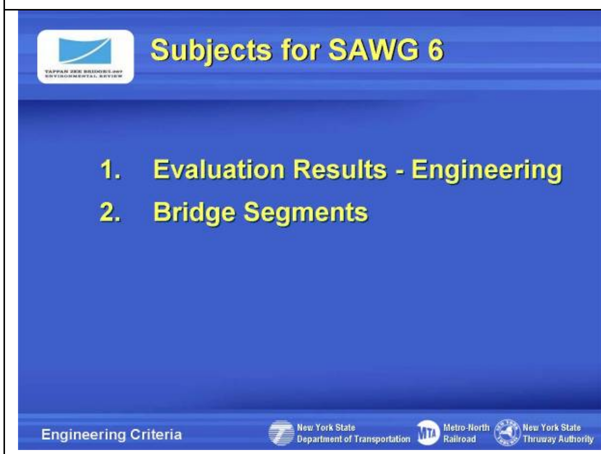


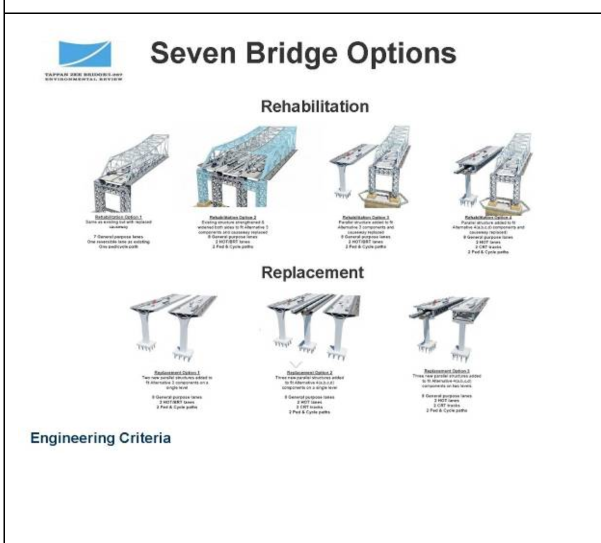
Slide 1:
Title slide.

This SAWG meeting was number 2 of 3 meetings to present the results of the “Alternatives Analysis for Rehabilitation or Replacement of the Tappan Zee Bridge.”

The previous meeting outlined the physical components of the seven bridge option. This meeting and the next present the evaluation criteria results.

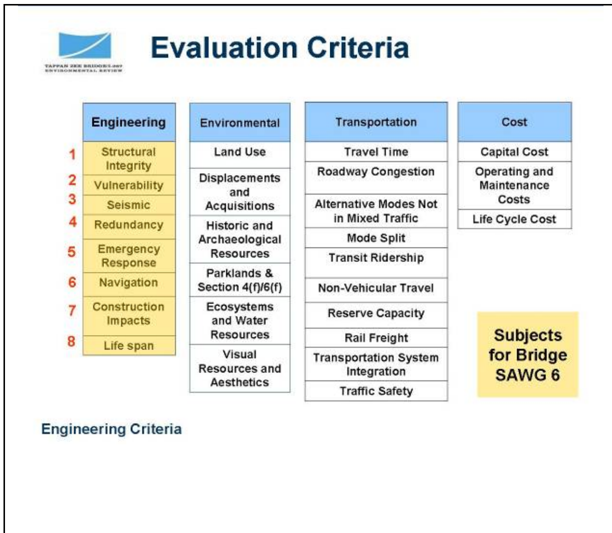


Slide 2:
This presentation was in two parts. The first summarized the results of the evaluation for the eight engineering criteria. The second part was a brief outlining the overall scale of work required for the existing TZB segments.



Slide 3:
This slide was a repeat from the previous meeting (BSAWG 5). The slide showed the arrangement of the seven bridge options being evaluated – four rehabilitation options and three replacement options.

This slide is repeated at the end of this presentation updated to include the foundation modifications required in the four rehabilitation options.

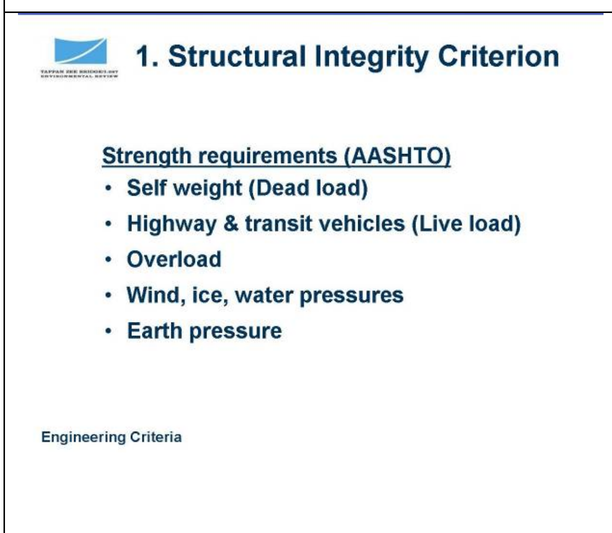


Slide 4:
This slide showed the full list of all the criteria evaluated for the bridge options. The first column lists the criteria discussed in this meeting.

Slide 5: Structural Integrity Criterion

This slide introduces the AASHTO bridge design specification which is the basis for all bridge design in New York State. AASHTO is the American Association of State Highway and Transportation Officials. This specification sets out the four requirements for bridge integrity. The requirements of this specification supplemented with the specific design requirements of the operating and maintaining agencies are the basis for the technical requirements within many of the engineering criteria.

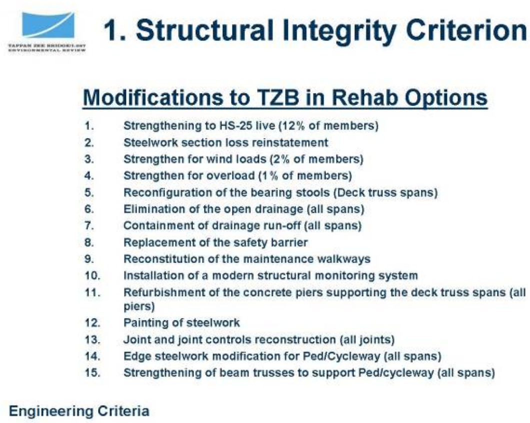
The first AASHTO requirement, as listed in the slide, relates to the provision of adequate strength, and is the source of technical requirements included in the Structural Integrity Criterion.



Slide 6:
This slide lists all of the loads to be supported by the TZB, as taken from AASHTO.

All seven bridge options had the ability to support all of the loads required by AASHTO and therefore complied with the requirements of this criterion.

While this criterion resulted in no discriminators between the seven options, the extent of the modifications required in the rehabilitation options was substantial.

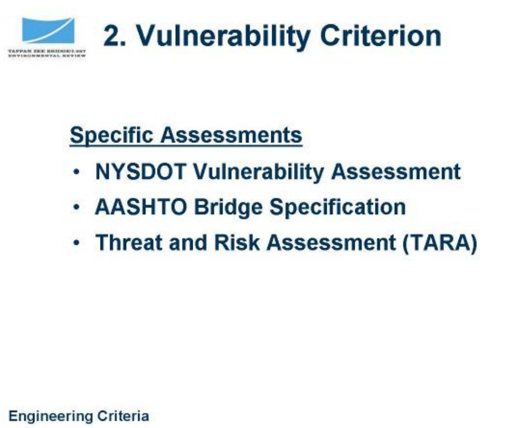


Slide 7:
This slide lists all the modifications necessary to the existing TZB in the rehabilitation options to meet the structural integrity criterion.

Post meeting note:
The standard highway loading HL-93 is to be incorporated instead of the HS-25 discussed at the meeting.

Slide 8:
This slide lists all the design requirements for the replacement bridge options to ensure structural integrity and sufficient strength to meet the AASHTO design requirements.

Post meeting note:
The standard highway loading HL-93 is to be incorporated instead of the HS-25 discussed at the meeting.



Slide 9:
This slide lists the three data sources/assessments used in the evaluation of the vulnerability criterion:

- An initial screening for possible vulnerabilities was conducted using the standard NYSDOT vulnerability assessment methods
- AASHTO also listed vulnerabilities to be considered as part of the service, fatigue and fracture requirements
- As required for all long span bridges a special threat assessment was conducted to ensure all potential vulnerabilities were considered.

<table>
<tr>
<td>

2. Vulnerability Criterion
(NYSDOT Vulnerability Assessment Results)

Engineering Criteria

</td>
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<u>Slide 10:</u>
This slide presents the results of the vulnerability screening completed using the standard NYSDOT vulnerability assessment methods. The method is a tool to prioritize potential vulnerabilities across a large number of bridges, and not an absolute indicator of vulnerability. A low rating is not a definite indicator of a concern but of the need for further assessment or inspection.

The results of the vulnerability assessment for the TZB indicated the need for further study of five of the six vulnerabilities considered, including vessel collision, overload, seismic, concrete details and steel details. The need for further assessment of potential hydraulics vulnerabilities (scour of the river around the bridge piers) was not identified.

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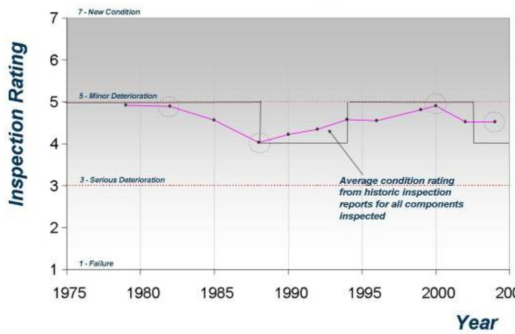
2. Vulnerability Criterion
(Overall condition rating)



Engineering Criteria

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<u>Slide 11:</u>
Based on the AASHTO bridge specification it is required that a bridge be serviceable with limits on cracking and deformations. This slide and those immediately following present some of the challenges that the NYSTA addresses to maintain the bridge serviceable.

The graph shown is repeated from the second bridge SAWG meeting and shows the cyclical nature of the maintenance requirements on the TZB. While the NYSTA has completed multiple repair contracts to keep the TZB safe, the rate of deterioration is high and continuous ongoing repairs are necessary. The upward movement of the graph corresponds to improvements in condition resulting from repairs and modifications completed by the NYSTA.

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2. Vulnerability Criterion
(Maintenance Challenges)

Engineering Criteria

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<td>

<u>Slide 12:</u>
This slide shows some of the concrete cracking and steel corrosion that has occurred on the TZB. While all of these particular items have been repaired, the continual occurrence of defects, and the extent of repairs are a maintenance challenge.

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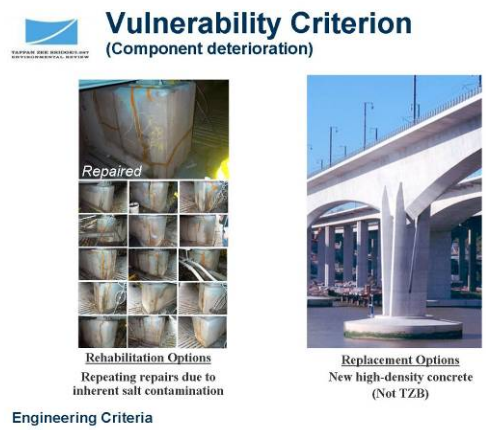


Slide 13:

This slide focuses on one particular maintenance issue on the causeway spans, cracking in the concrete column, and the extent of the deterioration.

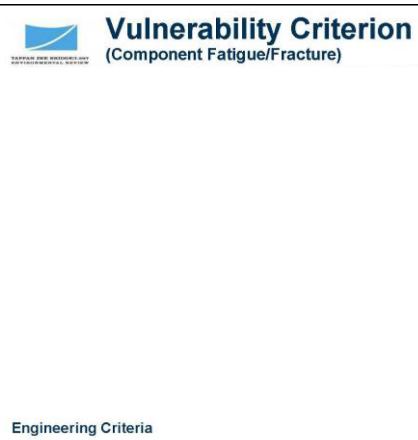
This type of cracking (image on the left) was present in 120 locations on the causeway spans. While one single defect can be repaired, the repetition of the defect at so many locations results in high maintenance costs and long periods of time for repairs. This defect is also significant, as it is the repaired column that has cracked, not the original concrete. This continuous reappearance of defects, is part of the cyclical maintenance cycle endured by the NYSTA to keep the bridge safe.

An image from a newly constructed pier from another bridge is shown on the right. The new concrete is free of defects with greatly improved durability resulting from the elimination of joints above and the quality of the concrete.

Slide 14:

This slide shows the bridge structure under the road deck on the main spans of the TZB. The presence of complex and layered steelwork in areas that are subject to splash from road salts has warranted particular attention by the NYSTA.

The historic exposure to road salts has increased the rate of deterioration of the steelwork and is a concern for the future.



Slide 15:

This slide shows some of the issues on the TZB related to steelwork fatigue. Fatigue is the technical term given to repeated loading of steelwork. To prevent failure of the steelwork there is a limit on the safe number of load cycles that can be applied. Overall fatigue is not a major concern for the TZB but there are some areas that the NYSTA is monitoring.

As an example, the top image shows a bottom plate welded to the steel stringer under the road deck. The weld at this location is prone to fatigue failure and has a limited safe working life. This steelwork is being replaced as part of the current deck replacement contract.

<table>
<tr><td></td><td>The other images show other steelwork details where fatigue was not shown to be a concern or the cause.</td></tr>
<tr><td>
</td><td><u>Slide 16:</u>

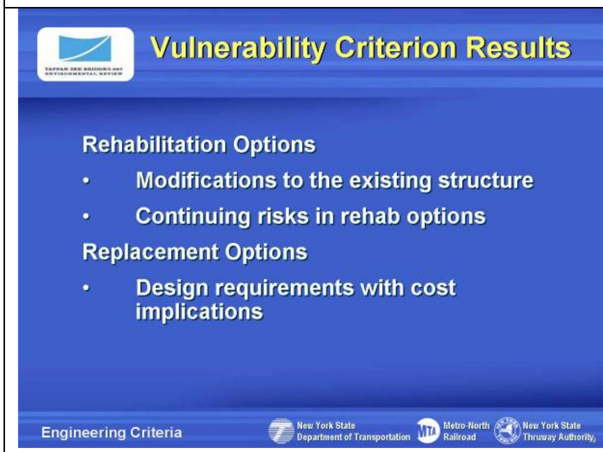
This slide was shown to highlight those areas of the main truss that were in tension. Tension areas require particular attention when considering fatigue or possible fracture of steelwork.</td></tr>
<tr><td>
</td><td><u>Slide 17:</u>

This slide presents a list of the issues highlighted in the AASHTO bridge specification that must be considered when designing bridges. These factors are more extensive than those highlighted in the NYSDOT vulnerability assessments, and introduce the need to consider actions from both accidental and deliberate sources.

To encompass the requirements of AASHTO and to ensure complete consideration of deliberate actions a more detailed assessment of the potential threats was completed, as reported in the next slide.</td></tr>
</table>

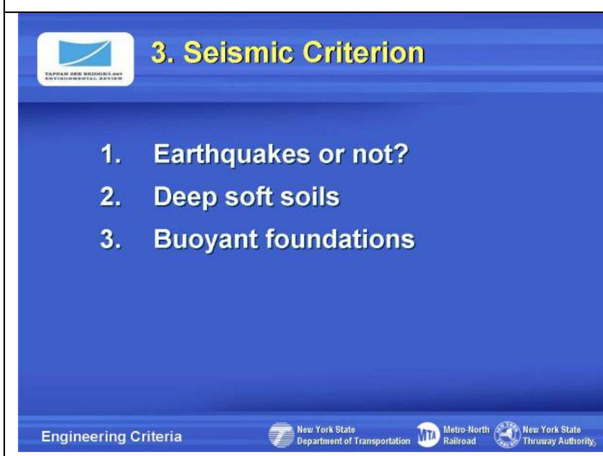
Slide 18:
This slide shows the results of the Threat and Risk Assessment (TARA) completed for the TZB. In this assessment the performance of the existing TZB was determined in 65 possible accidental or deliberate event scenarios. Event scenarios ranged from wind storms to deliberate action.

For security reasons more details of this TARA assessment can not be presented.



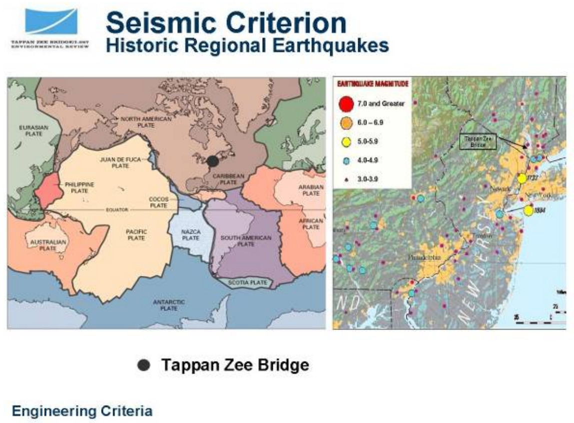
Slide 19:
This slide presents a summary of the result of all the vulnerability and threat assessments. Overall, to meet the requirements, there were design and cost implications for all options.

The poor performance of the existing bridge when considering malicious intent and deterioration was identified as a major discriminator between the rehabilitation and replacement options.



Slide 20:

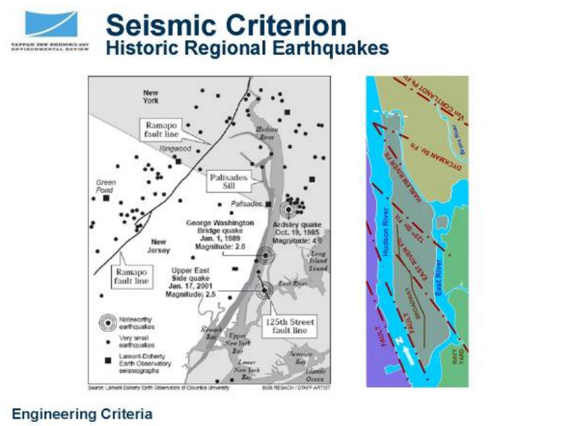
This slide listed the primary factors to be discussed as part of the seismic criterion.



Slide 21:

This slide shows the location of the TZB in relation to the tectonic plate boundaries. While the TZB is not on a boundary earthquakes have been recorded in the area from seismic activity at depth.

Also shown are the locations of historic earthquakes in the New York downstate area. Two earthquakes with magnitude greater than 5.0 have been recorded in relatively recent history.

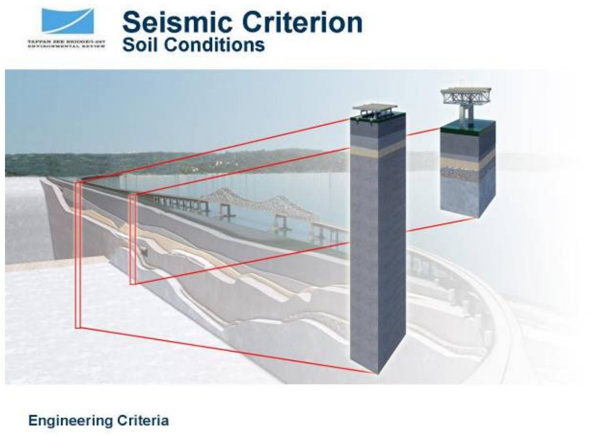


Slide 22:

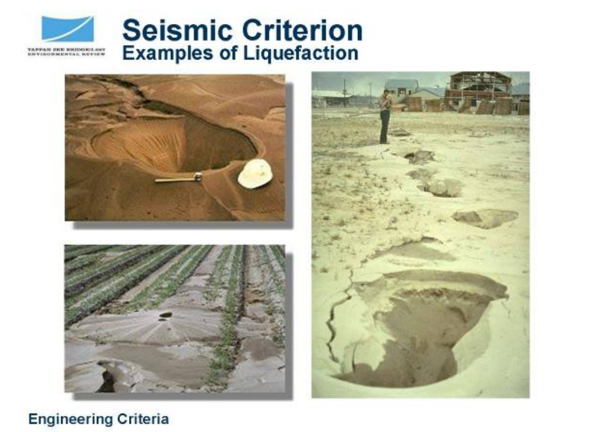
This slide shows the location of the known faults in the area of the TZB and through Manhattan. As new seismic events occur additional faults continue to be defined.

Slide 23:
This slide is repeated from an earlier bridge SAWG meeting and shows the soils underneath the Hudson River. These deep soft soils, particularly in the western half of the river, amplify the characteristics of an earthquake thus increasing the seismic demands on the bridge foundation and structure.

Note the vertical scale of the soil layers beneath the Hudson River are exaggerated for clarity.

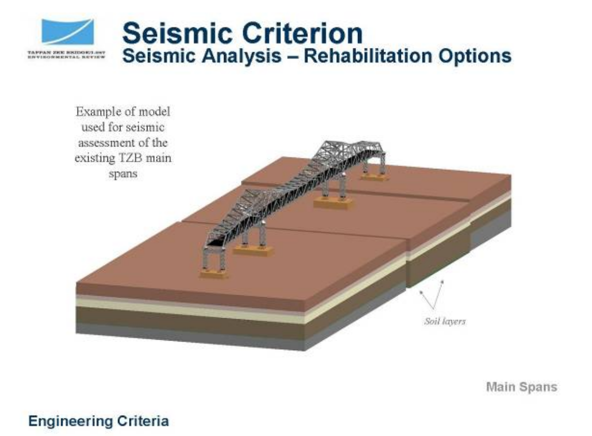


Slide 24:
This slide shows the variation in soil conditions at two different locations in the Hudson River. The different soil conditions result in different seismic demands at different locations. The soft soils, in the western half of the Hudson River, below the existing causeway spans, are unusually deep and warrant close attention for any new structure.



Slide 25:
Slide shows examples of soil liquefaction, a phenomenon similar to quicksand that occurs when the ground is shaken violently. Liquefaction results in loss of soil strength with the potential for major deformation of the foundations of bridges or buildings. The images shown were taken of liquefied soils in the aftermath of seismic events.

Liquefaction would not occur at the TZB. Extensive testing of the soil has resulted in the elimination of liquefaction as a factor in the seismic assessment of the rehabilitation or replacement options.



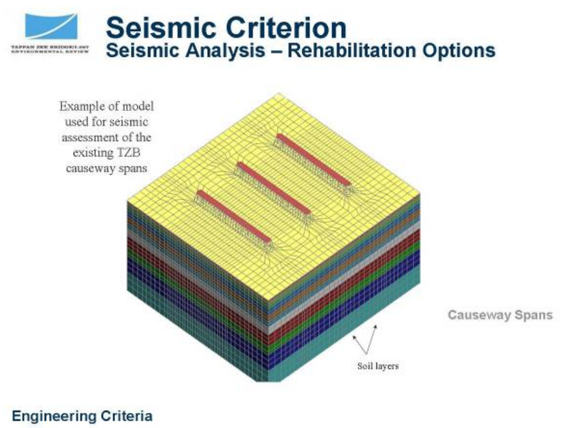
Slide 26:
This slide shows a graphic of the structural model of the main spans of the existing TZB. During the SAWG meeting a movie was shown of how the structure behaves during a seismic event. In particular, attention was focused on the behavior of the 'buoyant' foundations.

The analysis showed that the seismic demands were greater than the capacity of the existing structure in a number of locations. These demands were greatest at the base of the buoyant caissons at the connection with the piles below. The seismic demands were well above the typical safe working limit.

Slide 27:
While the safe working limit was exceeded, this did not necessarily mean that the performance of the TZB was unacceptable, but was only an indication that damage would occur.

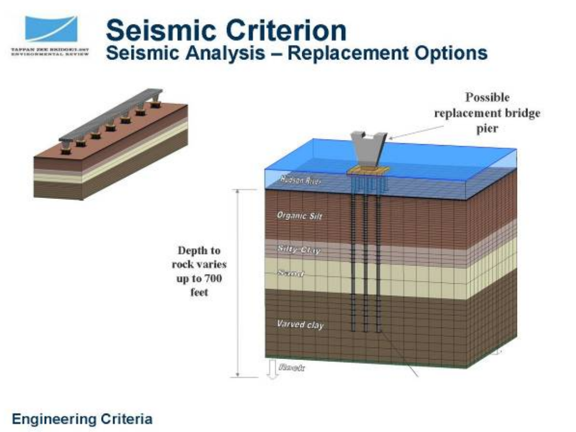
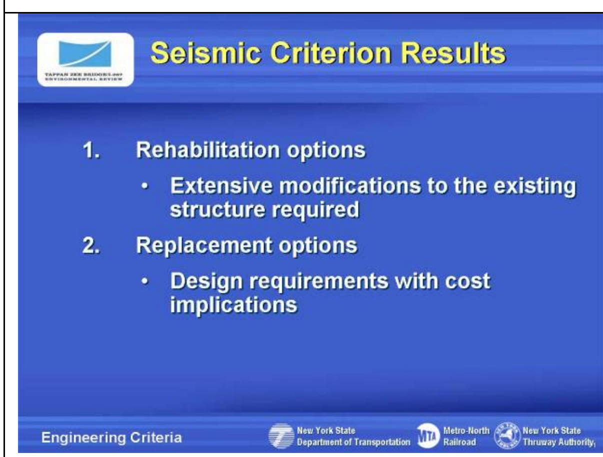
To determine how much damage would occur a more detailed local analytical model of the caisson to pile connection was developed and tested. The results indicated widespread cracking at the base of the buoyant caisson that would allow water to penetrate through the concrete. This flooding of the caisson would result in a loss of buoyancy affecting the overall stability of the main spans, with the potential for major settlement or collapse.

The extent of potential damage was much greater than that which could be repaired in the timescales set out in the NYSDOT/AASHTO specifications. As a result it was concluded that modifications were required to the foundations of the existing TZB to meet current seismic requirements.



Slide 28:
This slide presented some of the results of the seismic assessment of the causeway spans. Though the causeway spans are to be replaced in all the options, the seismic performance of the causeway spans was discussed.

As shown in the movie played the seismic movements of the foundations were substantial with large seismic demands resulting in unacceptable damage to the overall structure.

 	Slide 29: This slide highlighted the need for special steel reinforcement arrangements inside concrete columns to ensure predictable seismic performance and controllable damage. The columns supporting the TZB do not have the special steel reinforcement arrangement required. In particular, the horizontal (hoop) steel was inadequate and as a consequence substantial modification to the existing columns was required as part of the rehabilitation options. The images shown are not of the TZB.
 	Slide 30: This slide shows the analytical models used in the seismic evaluation of the new structure in the replacement options. A movie showing the typical behavior of a new bridge in the area of the soft soils was presented. Movements of the soils, piles and structure were shown in one model to combine complex interactions that occur during seismic events. For the span lengths of 230 feet used, 9 steel piles supporting each pier were shown to be sufficient to accommodate the demands of the design seismic events. The piles extended up to 300 feet below the riverbed.
 	Slide 31: This slide presented a summary of the seismic criteria results. The extensive modifications required in the rehabilitation options included full foundation replacements at the eight buoyant caissons. The size of these foundations was larger than the comparable foundations in the replacement options. For the replacement options, particularly in the soft soils in the western half of the Hudson River, this criterion resulted in increased cost for the deep piles required.

Seismic Criterion Results
Foundation Comparison

Rehabilitation Option 3 — Replacement Option 1

Engineering Criteria

Slide 32:

This slide shows a comparison of the resulting foundation sizes for representative rehabilitation and replacement options.

The new piles are shown in grey and white with the existing foundation in light brown.

4. Redundancy Criterion

Scenario (Single Event)	Rehabilitation Options 1 and 2	Rehabilitation Options 3 and 4	Replacement Options 1, 2, & 3
Explosion	Potential loss of all highway capacity for one or more years	Potential loss of one half of the bridge for one of more years	Potential loss of one half of the bridge for days or weeks
Ship allision with main spans	No loss of service – impact protection provided		
Seismic	Loss of service for months		

Engineering Criteria

Slide 33:

This criterion was a measure of the performance of the options under representative event scenarios.

For ship allision and seismic events all options performed the same. However, when considering some events, there is potential for loss of half the crossing for one or more years in the rehabilitation options compared to days or weeks for the replacement options. The poorer performance of the rehabilitation options is a consequence of the structural form of the main span, where the loss of one of many key members has the potential to result in disproportionate impact.

An allision is a collision in which one object is stationery.

5. Emergency Response Criterion

- **Provision of highway shoulders**
- **Track or structure crossovers**
- **Access to CRT incidents**

Engineering Criteria

Slide 34:

This slide lists the discriminators for the emergency response criterion. The primary discriminator was the absence of highway shoulders in rehabilitation Option 1, which would restrict access for emergency vehicles.

6. Navigation Criterion

Engineering Criteria

<u>Slide 35:</u>
No discriminators were identified in the navigation criterion among the options. Although the shipping clearance could be increased with a new bridge this was not a requirement and therefore not a discriminator among the options.

6. Navigation Criterion
Bridge Clearance

Bridge	Clearance (feet)	
	Vertical	Horizontal
New York Harbor – Verrazano Narrows (I-278)	229	
New York Harbor – Bayonne (SR 440)	151	1,652
George Washington (I-95)	213	3,169
Tappan Zee Bridge (I-287)	139	1,042
Bear Mountain (SR 6)	155	1,632
Newburgh Beacon (I-84)	172	960
Middle Hudson Suspension (US 44)	134	1,080
Fixed Bridge Highland landing to Poughkeepsie ConRail	167	490
Kingston Rhinecliff (SR 199)	135	760
Rip Van Winkle (SR 23)	142	480
Railroad Fixed (South of I-90)	139	566
Castleton on Hudson Fixed (I-90)	135	552

Engineering Criteria

<u>Slide 36:</u>
This slide presents a summary of the shipping clearances for the bridges on the Hudson River and adjacent waterways.

In the lower reaches of the Hudson River the TZB, at a clearance of 139 feet, is the height restriction on the river.

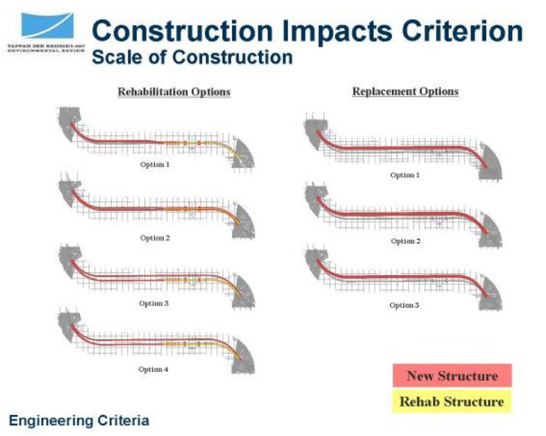
7. Construction Impacts Criterion

- **Scale of Construction**
- **Construction Duration**
- **Work in the Hudson River**
- **Maintenance and Protection of Traffic**

Engineering Criteria

<u>Slide 37:</u>

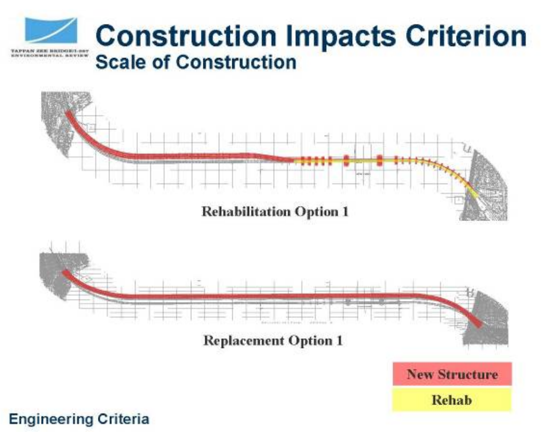
This slide lists the four issues found to be of significance when considering the construction impacts criterion. These four topics are outlined in the next slides.



Slide 38:
This slide highlighted the extent of work required in each option. The new construction is shown in red.

Because of the need to replace the causeway and replace many foundations in the rehabilitation options, the extent of work in the river is of similar scale to that required in the replacement options.

In rehabilitation options 3 and 4, approximately 80% of the structure is new and is exactly the same as the replacement options.



Slide 39:

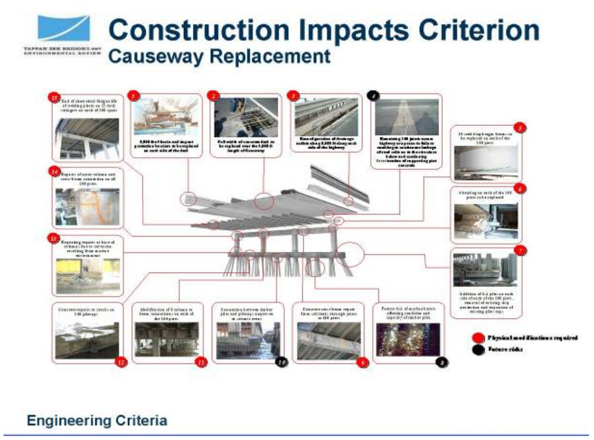
This slide shows a closer view of rehabilitation option 1 and replacement option 1. Because of the extensive foundation works required in the rehabilitation option as a result of the seismic criteria, the number of piles and new foundations required in the Hudson River in both options is of similar magnitude.

Even for rehabilitation option 1, the smallest of the rehabilitation options, the scale of river works is the same for the full new bridge in replacement option 1, which included full 8 lanes, full shoulders and provision for BRT transit.

Slide 40:

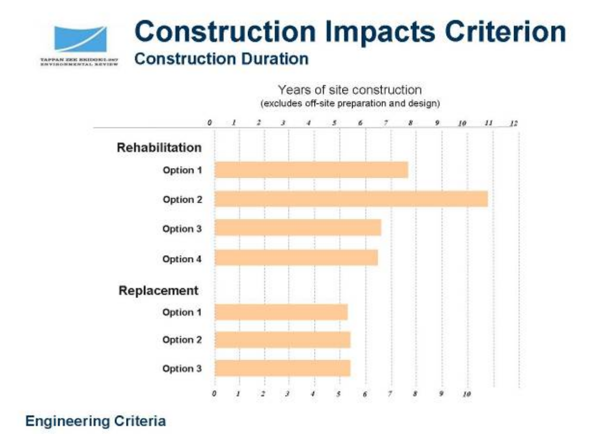
This slide shows the extent of construction works that would be required for the causeway spans. All 166 spans would require extensive foundation enlargements, substructure upgrade, as well as superstructure reconstruction.

The causeway spans are replaced in all options.



Slide 41:
This slide presented a summary of all the construction, safety and maintenance issues associated with the existing causeway spans. Also included are inherent future cost and condition risks.

The extent of the issues and future risks were the basis for the decision to replace the causeway spans in all the rehabilitation and replacement options.

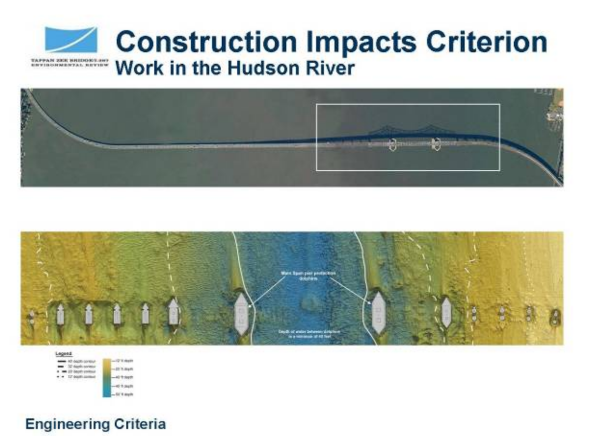


Slide 42:
This slide shows the approximate construction duration for the seven options.

At just over 5 years, the shortest construction period is associated with the replacement options. The new replacement bridges would be open after 4.5 years with the remaining six months necessary to remove the existing TZB.

The construction duration for rehabilitation option 2 is the longest because of the extensive modifications necessary to the existing structure and the need to work in close proximity to the existing 7 lanes of traffic.

The construction duration for the remaining rehabilitation options is between the above extremes.



Slide 43:
This slide shows a shadow relief diagram of the riverbed adjacent to the foundations of the existing TZB. The image shows some scour patterns as well as deposition of material on the north and south side of the existing foundations.

For the rehabilitation options, new foundations would be required right up against the existing foundations in the areas of deposition or erosion. The foundations for the replacement options would be located at some distance offset from the existing foundations.

Because of the need to remove the existing foundations in the replacement options, the overall scale of construction works in the river was considered to be of similar magnitude for the rehabilitation and replacement options.

Construction Impacts Criterion
Maintenance and Protection of Traffic

Rehabilitation Option 2

Engineering Criteria

Slide 44:
This slide shows a close up of the widened main span for the rehabilitation option 2. This option would require enlargement of the existing two trusses of the main span while keeping the existing seven traffic lanes in operation.

The risks associated with construction adjacent to live traffic and the scale of the changes required to the existing trusses is of such magnitude as to justify elimination of this option when compared to the benefits of rehabilitation option 3. In that option all modifications can be made to the existing TZB while traffic is relocated to the new supplemental bridge.

As will be shown in the next SWAG meeting there are also notable traffic safety concerns with rehabilitation option 2.

8. Lifespan Criterion

Duration until major repairs are anticipated		
Component	Rehabilitation Options	Replacement Options
Concrete Deck	40-50 years	100 years +
Bearings	40-50 years	50-100 years
Concrete Columns	20 years	100 years +
Foundations	100 years +	100 years +

Engineering Criteria

Slide 45:
This slide shows the last of the engineering criteria – lifespan. While the TZB does not have an overall lifespan, a lifespan can be attributed to the various components that make up the bridge.

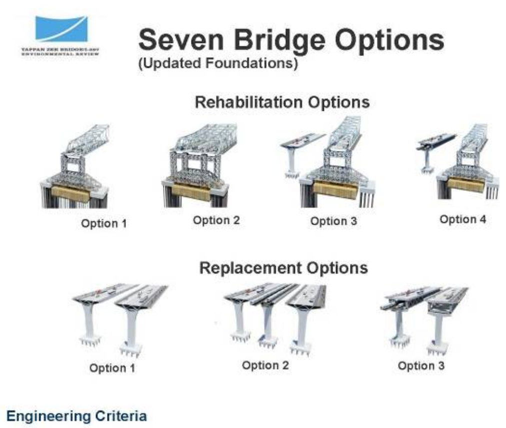
As shown in the slide, the replacement bridge options have a longer lifespan – up to 100 years before major repair as required by the NYSTA. The lifespan of the components of the rehabilitated TZB is shorter as many components have inherent contamination, as demonstrated by the repair cycle presented earlier in this presentation. For example, major repairs on the concrete in the retained piers would be expected at 20 year intervals, matching the historic record.

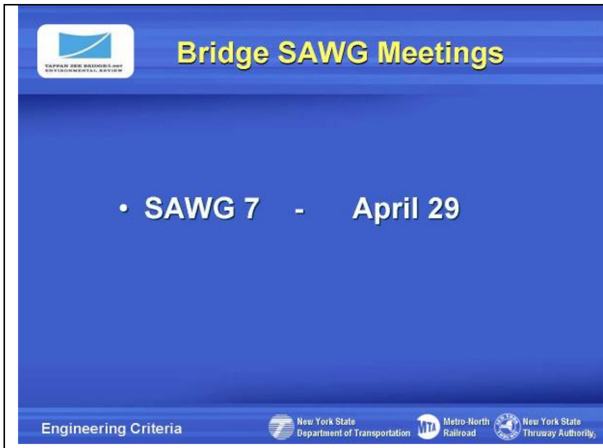
Subjects for SAWG 6

1. Evaluation Results - Engineering
2. Bridge Segments

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

Slide 46:
This was a title slide introducing summary slides for the various bridge segments.

Rehabilitated Deck Truss Spans Engineering Criteria	<u>Slide 47:</u> This slide showed the extent of all the changes required to the deck truss spans in the rehabilitation options.
Rehabilitated Main Spans Engineering Criteria	<u>Slide 48:</u> This slide showed the extent of all the changes required to the main spans in the rehabilitation options.
	<u>Slide 49:</u> This slide was a repeat of a slide shown earlier in the presentation but this time included the final foundations required in all options. These foundations primarily resulted from the requirements of the seismic criterion.

 	Slide 50: The next SAWG meeting was scheduled for Tuesday, April 29.