MEMO

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SUBJECT: Conceptual Modes of Failure of the West Seattle High Bridge

DATE: May 15, 2020

The West Seattle High Rise Bridge is currently closed to traffic to protect the traveling public. The decision to close the bridge was due to cracks in the structure and their association with the bridge's structural capacity.

The City of Seattle, owner of the bridge, requested that WSP, the City's structural engineer, provide a description of potential failure mechanisms. Some more immediate mitigating actions, such as removing the live load (vehicle traffic) and continuous monitoring, have been implemented. Other actions, such as designing the temporary and permanent stabilization repairs, are just beginning. WSP is taking other actions to address the bridge's short- and long-term performance, all in close coordination with the City of Seattle.

It is important to note that concrete structures, including bridges, do routinely exhibit cracking, and so concrete structural design includes reinforcing to address cracking. However, in this case, the cracking at four similar locations has rapidly progressed, and it must be determined whether or not this cracking could lead to the collapse of certain portions of the bridge.

The following summarizes potential failure mechanisms, or modes of failure, that could lead to the collapse of portions of the bridge. See attached figures that accompany the narrative.

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1. Failure/Collapse: Potential Modes

a. Cracks Could Keep Progressing and Stop

The bridge is currently exhibiting progressive crack growth at two critical locations (Joints 38) of the four quarter points of the twin-box main span between Pier 16 and Pier 17. This is where the first failure mechanism has appeared. While a progressive failure does not mean collapse is imminent, it does illustrate an unintended redistribution of forces within the bridge that could lead to further damage.

The cracks have opened and propagated where the internal reinforcement has yielded (stretched) but has not broken. The cracks, without any mitigation, could stop, and the bridge could redistribute load until internal forces stabilize. However, this is not considered likely as the bridge will continue to creep (slowly deform under static load) over time and thus continue to crack.

b. Partial Collapse

A second mode of potential failure would be a partial collapse. The damage in this mode depends on the integrity of the existing post-tensioning in the deck and the webs of the box girder. If these reinforcing elements rupture (break), or if there is pull-out of the post-tensioning (high-strength steel tendons) from the deck or their anchorage, then partial collapse, the second mode of failure, is more likely.

The second mode could occur in one of two ways. One scenario is symmetrical, in which pieces of concrete detach and begin falling from the bridge at both critical locations. The distress could continue simultaneously with a portion of the main-span bridge box girders separating and falling into the waterway below. It is possible that due to arching effects, portions of the deck remain but in severely deflected state.

The other partial collapse scenario is an asymmetrical collapse, in which pieces of concrete at one location detach and begin falling from the bridge, and then a shorter portion of the main-span bridge box girder separates and falls below. This would result in an unbalanced condition, with overloading of the long cantilever extending out from the opposite pier.

In both scenarios it is possible to load the columns with unbalanced loads, creating damage in the columns. It is also likely that tensile or bending damage to the back spans between Piers 15 and 16 and Piers 17 and 18 would occur due to the removal of beneficial balancing load from the center span.

Both second mode of failure scenarios would require the bridge to be either partially or completely demolished. The remaining portions of bridge superstructure and foundations may be salvageable if they sustain no or minor damage.

While it is possible that failure could include some lateral disbursement of concrete, we believe it is more likely that a potential collapse would occur directly beneath the bridge. However, it would be prudent to create a plan to evacuate the area the area within a 45-degree projection from the bridge's vertical edge. Additionally, such an evacuation plan should include a portion of the approach-structure spans that are adjacent to the main high-bridge structure. Conservatively, this could include the first two adjacent spans of the approach structures on either end of the main span.

2. <u>Mitigations Needed in Light of Partial Collapse Risk</u>

In light of the potential for partial collapse of the bridge, the following is a list of mitigations in order of priority:

1. Continue daily visual inspections of the structure.
2. Implement an automated survey system that collects data in real time, with manual surveys in the near term until the automated system is functional.
3. Implement localized deformation data logging using an automated system that will report total deformation across multiple cracks.
4. Undertake non-destructive testing (NDT) of select vertical post-tensioned tendons in the webs.
5. Design and construct interim repairs at the distressed locations to arrest the crack propagation in the near term.
6. Repair the bearings at Pier 18 that are restricting thermal expansion and contraction movements of the structure.
7. Design, fabricate, and deploy temporary shoring to support the bridge in case of partial or multi-span superstructure collapse.
8. Evaluate full repair alternatives relative to the potential need for bridge replacement.

9. Design and construct full repairs if feasible or demolish the bridge and plan for a bridge replacement.

3. <u>Closing Remarks</u>

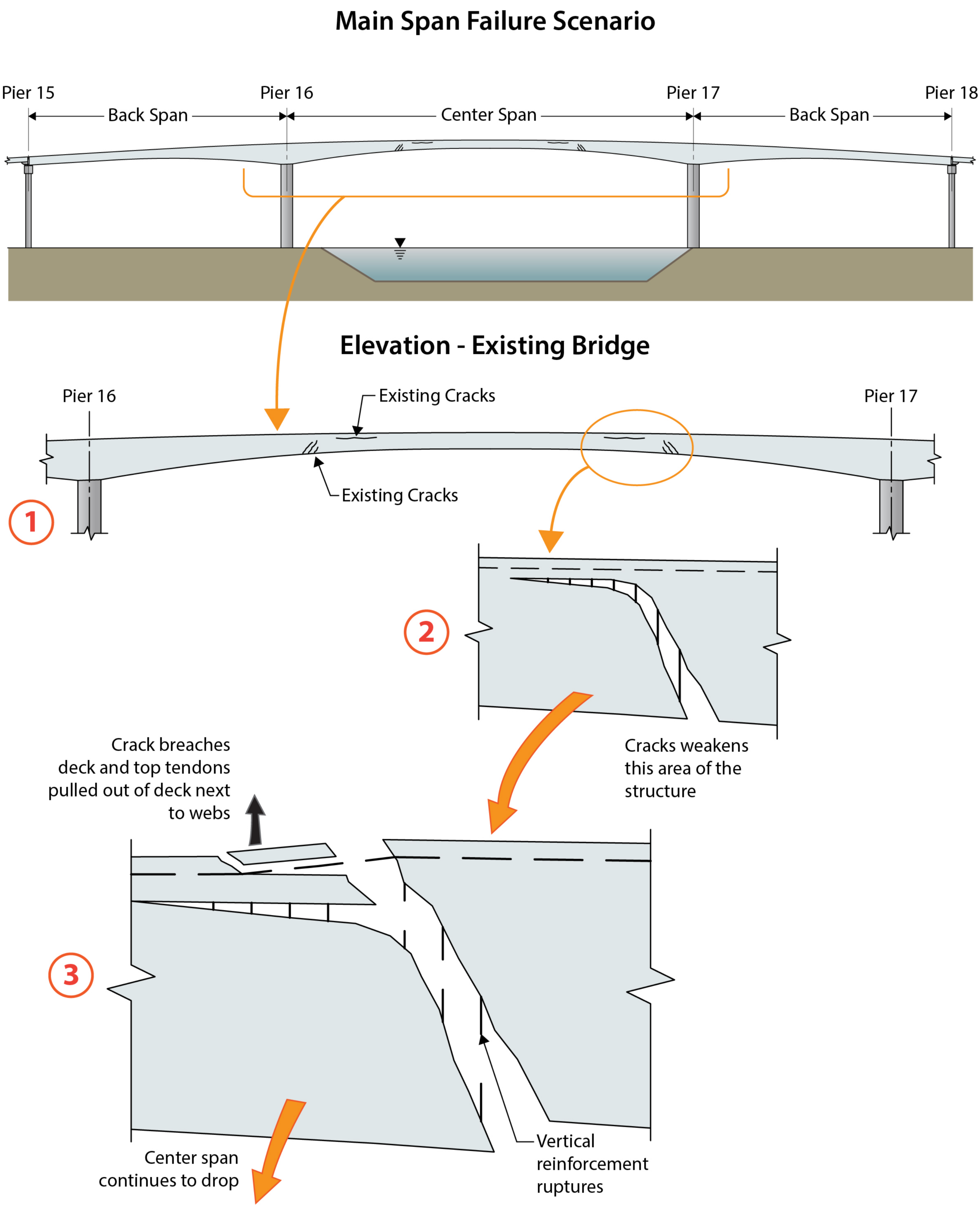
This bridge's issues are unique, and we are not currently able to indicate the likelihood of any of the potential failure scenarios. We do not have probabilistic data for comparison with other structures or other risks. While some risks to bridges, such as earthquakes, have been studied extensively, and so the probability and/or causes of failure are better understood, this bridge's problems do not fit into a probabilistic failure-prediction framework.

The time it could take to reach each mode of failure is also unknown with the current data. Survey and displacement data from electronic sensors currently being installed will give us real time information on the bridge's behavior and alert us to unusual rates of change that should precede a potential failure scenario. The previously observed acceleration in the cracking could indicate that the risk of failure is increasing, and the time to potential failure shortening. As we gather survey and displacement data, we will be able to better determine whether the cracking is accelerating, allowing us to more accurately predict possible failure.

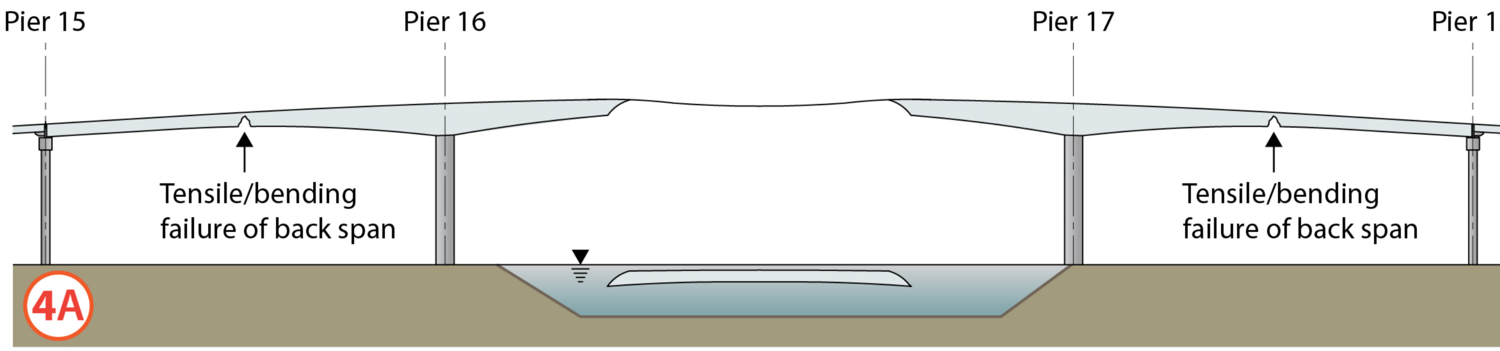
In the event that we anticipate an imminent potential failure, safety actions – including notification of the public, stakeholders, and partner agencies – would have to be deployed rapidly, just as the original bridge closure was precipitated by short-term observed changes to the cracking.

The temporary crack arrest measures and the release of the Pier 18 restrained bearings are intended to halt further damage and provide temporary stability where there is cracking, minimizing the potential for collapse. Simultaneously, we continue to collect data and explore future actions to permanently restore the bridge's integrity.

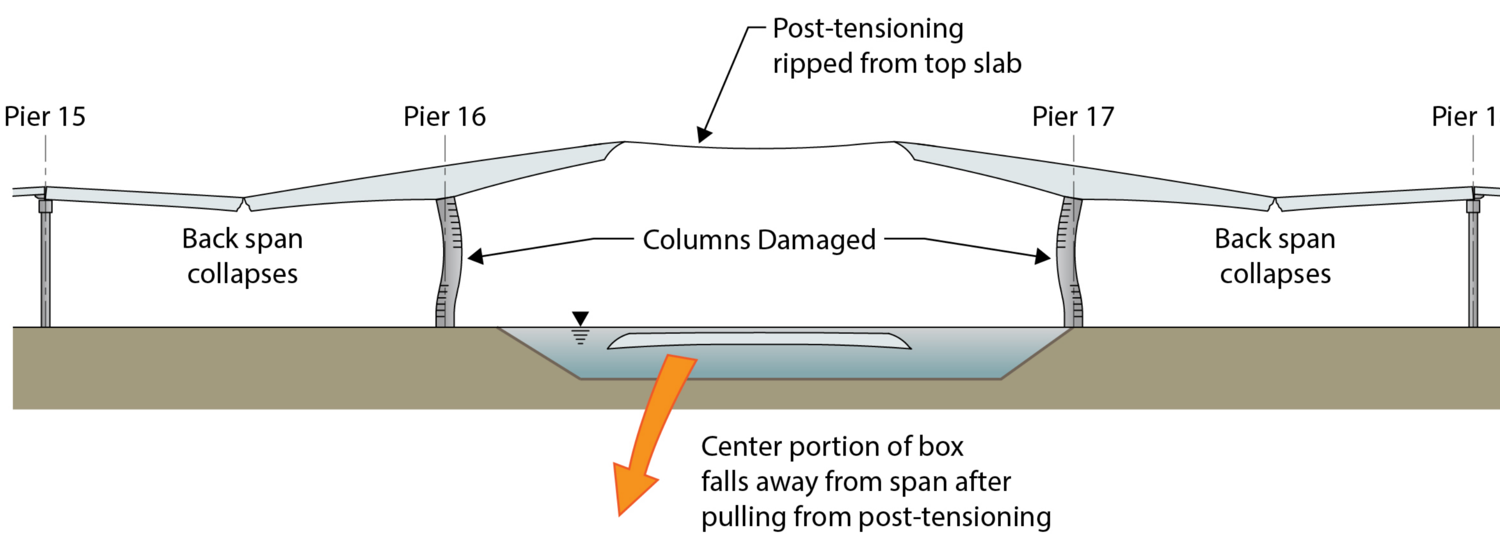
We would be happy to meet with you and your team to discuss the memorandum and answer any questions you might have.


Main Span Failure Scenario
Pier 15
Pier 16
Pier 17
Pier 18
Back Span
Center Span
Back Span
Elevation - Existing Bridge
Pier 16
Existing Cracks
Pier 17
Existing Cracks
1
2
Cracks weakens this area of the structure
Crack breaches deck and top tendons pulled out of deck next to webs
3
Center span continues to drop
Vertical reinforcement ruptures

Symmetric Bridge Failure Scenario

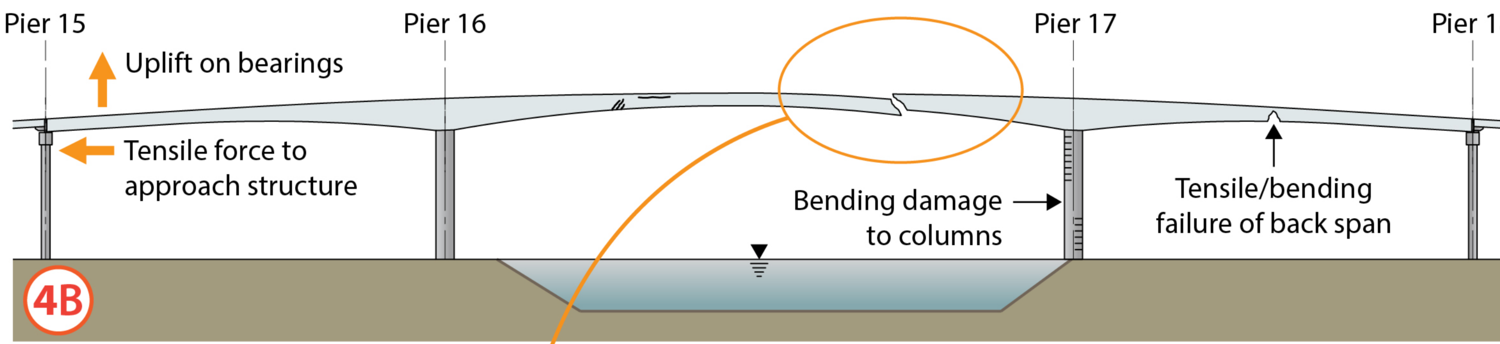


Elevation

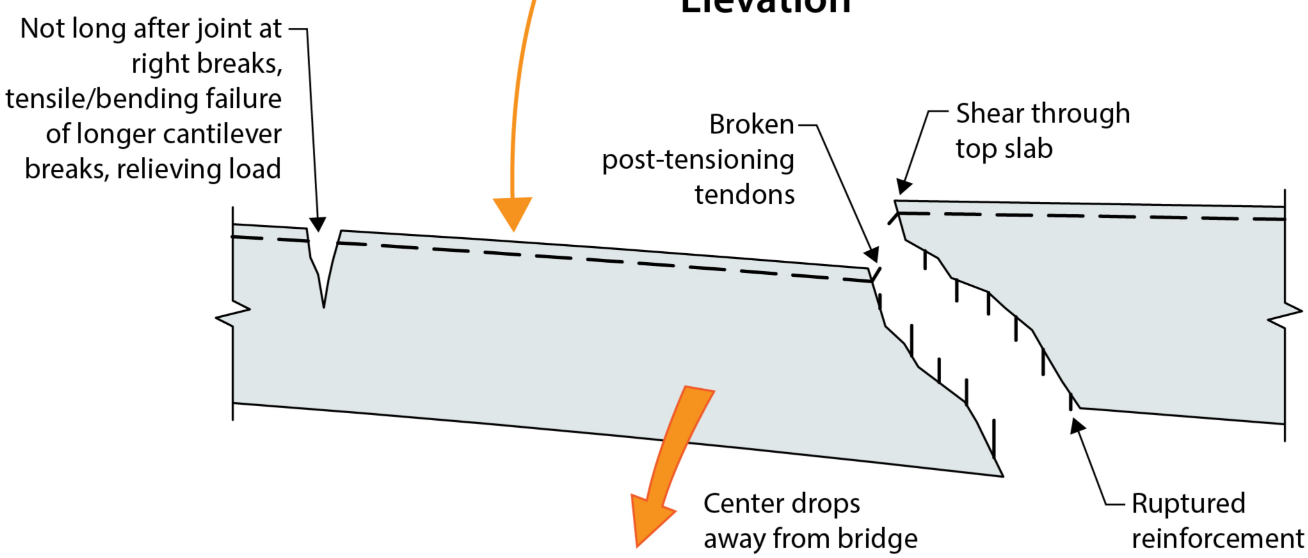


Detail

Asymmetric Bridge Failure Scenario



Elevation



Detail