Received March 20, 2020

From: Banks, Greg
Sent: Friday, March 20, 2020 11:28 AM
To: Donahue, Matthew
Cc: Warner, David C.; Marsh, Lee
Subject: RE: WSHB - Recommendation Update

Matt:

I'm following-up on WSP's recommendation in the email below and our conversation yesterday to close the bridge. Since our initial recommendation, our biggest concern has become the extent and rate of cracking near the quarter points of the main span could lead to collapse in the near future if strengthening is not implemented quickly. Our prior recommendation was based on the cracks being essentially static, as also assumed in our technical analysis. The cracks are elongating, and this is the single biggest factor in our change of recommendation. This is supported by the following points that have become clear since our initial recommendation:

1. This bridge has several complications that we cannot model analytically, and these make interpretation of behavior less quantitative than we would like. This is combined science and judgment.
2. The cause of the cracks at the interface between the deck and the web is not fully understood and is not included in our modeling.
3. Observed crack propagation rates of the diagonal web cracks are high and cause concern that the process is accelerating in some fashion we cannot quantify.
4. As previously discussed, if the active web diagonal cracks and existing cracks near the deck-web connection at the top of the box meet into one combined system of cracks, then a potential collapse mechanism could form. The recently noted changes indicate we need to be more concerned about this failure occurring because the shear capacity of the cracked region is very sensitive to the rotations of this joint region.

The email attachment provides more detail related to the matter. I am also available at any time to discuss.

Regards-

Greg Banks; PE, SE
Project Manager

BergerABAM is now WSP.
Please note the new email address.

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For the purpose of the following discussion, there are three types of cracks.

1. There is cracking in the bottom slab.
2. There is diagonal web cracking (the cracks that were observed to have originated in the bottom slab in 2013).
3. There are horizontal cracks between the top of the web walls and the bottom of the roadway slab. These horizontal cracks are also accompanied by a pattern of small diagonal cracks at the top of the web near the pier-side end of each superstructure segment. For the purpose of this discussion we will refer to this third type of cracks simply as the "deck-interface cracks".

The diagonal cracking has propagated diagonally up through the webs, and some of the cracks have grown to within 11-inches of the bridge deck-to-web interface. The bottom slab cracking and the diagonal cracking are related and indicate yielding of the mild streel in the lower portions and bottom slab of the box sections. This has essentially created a hinged joint between the two portions of the bridge on either side of this region of cracking. For the purpose of this discussion this region will be called the joint, or hinge.

A characteristic of the hinge is that it is free to rotate unless restrained. In this case the rotation of the hinge is largely restrained by the structure's self-weight. However, live load causes small transient, but limited, rotations of the hinge, and more significantly, temperature changes and time-dependent creep of the bridge's concrete cause opening rotations of the hinge. The creep effect means restraint is slowly being relieved over time and the joint will continue to open. We previously expected this opening to be a very slow process, possibly taking years to notice significant changes. However, the recent increase in the length of the diagonal cracks indicate the process is occurring faster than expected.

The diagonal cracks were epoxy injected in August 2019, and as of today some cracks have propagated further. We (WSP) have been inside the box girder three times since then; in October 2019, December 2019, and in March 2020. Observations of the diagonal cracking are as follows:

- In **October 2019** we could see evidence of cracks that had been marked in the past, but we could not define the extent of the cracks themselves.
- In **December 2019** we could see the all the cracks that had been previously marked, and observed that the cracks had extended beyond the previous markings. Cracks were traced with black marker to the extents that were observed. These extents were also marked with a date.
- In **March 2020** some of the cracks were observed to have again increased in length from what was observed in December 2020; approximately 6-inches to 12-inches further. The growth of the cracks were marked and dated with a black marker.

About the observations in March, not all the diagonal cracks have increased in length. From our review of the March inspection photos, the cracks that have increased in length appear to be those that terminate farther from the deck interface. This is an important observation. It indicates the joint is opening faster than we initially thought possible, which means the restraint provided by the rest of the structure is going away faster than we thought. Also, as cracking becomes more extensive, more load is transferred from the concrete to the reinforcing steel causing the structure to approach its full-strength capacity. Our analysis effort demonstrated that the strength of the bridge is very sensitive to this restraint and resulting "rotations" at the joint area created by the diagonal cracking. This is the fundamental reason of our heightened concern for the bridge.

The presence of the deck-interface cracking also continues to be a concern. The origins of these interface cracks, and their associated short diagonal cracks near the pier-side end of the segment, are unknown. In fact, we have been advised by Collins and associates that their analysis tool is not specifically designed to capture this behavior. This aspect of the analysis is another recent understanding gained from the analysis effort. That said, interpreting the impact of these cracks on the overall behavior of the bridge is still needed. The location and size of these cracks imply that the reinforcement that crosses these cracks is being used to resist forces not associated with the joint 38 hinge behavior described above. If this is so, then these cracks have already “consumed” some of the very web strength capacity that the bridge now needs. Given the unknown origin of the cracks, we must take a conservative approach to discounting the structural strength that these deck-interface cracks consume, and this has contributed to our increased level of concern related to bridge stability.

Through discussions with Dr. Evan Bentz of the University of Toronto, it appears that the bridge may be forming crack patterns consistent with reaching a collapse mechanism. It is not anticipated that a collapse mechanism is imminent. However, we can no longer assume that we are witnessing a very slow process and that the structure is stable enough to rely on the analysis showing it currently has capacity to carry at least two lanes of traffic.

In summary, the behavior we are witnessing, and have described above, goes beyond the key assumption on which our analysis is based, that the cracking is essentially stable. Because of this assumption we believed the bridge would be adequate for reduced usage because the cracks were static, in that the diagonal cracking would not meet up with the deck-interface cracking and that we would have time to look into the nature of the interface cracking.

Since this recommendation, we have come to learn that these cracks are not static, but that they are dynamic; they are extending, and if they continue to propagate, a failure could result. This requires a new recommendation, a recommendation to shut the bridge to operations now, and repair it immediately.