THE NEW SAS BAY BRIDGE- CURRENT PROBLEMS WITH SUGGESTIONS FOR SEISMIC RETROFIT

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Elevation and Plan View of the SAS (Self-Anchored Suspension) Bay Bridge
List of Major Problems of the New SAS Bay Bridge

1. Hydrogen-Embrittled Bolts in Saddle Connections
2. Likely Seismic Local Buckling of Tower Shafts
3. Hydrogen-Embrittled Bolts in Cable Connections
4. Uplift at the Expansion Joint
5. Fracture of Guardrail Bolts
6. Cracks in the Deck Welds
7. Cracks in the Tower Field Welds
8. Fracture of Tower Anchor Rods
9. Salt Water inside Pile Cap
10. Questionable Pile Welds
11. Questionable Concrete in the Piles
12. Corrosion of the Main Cables
13. Water Inside Steel Deck
14. Expansion Joint at Mid-span
15. Fractured Anchor Rods in Seismic Shear Keys
A. Likely Seismic Local Buckling of the Tower Shafts

The Performance Criteria established for this “lifeline” bridge by the design documents states that:

“The bridge shall have a clearly defined inelastic mechanism for response to lateral loads and inelastic behavior shall be restricted to piers, tower shear links, and hinge beam fuses.”
Realistic Pushover Analysis
Transverse and Longitudinal Pushover Curves

(a) At Yield (Point Y)           (b) At Max. Strength (Point U)       (c) At Point where Ductility is Measured (Point D)
Possible Retrofit to Prevent Local Buckling of the Tower Shafts

- **Retrofit Option 1:** Add Bolted WT-Section
- **Retrofit Option 2:** Add Welded Pipe
- **Retrofit Option 3:** Add Welded Channels

**Regions of Tower Local Buckling at the Maximum Strength Point**

- **Local Buckling**
- **Zone of Local Buckling**
- **390 ft (99 m)**
More than 2,200 anchor rods and bolts used in the new SAS Bay Bridge are A354 BD hot-dip galvanized. They are all hydrogen-embrittled.

In 2013, 32 of these bolts fractured when tightened.

In 2015, two of the tower anchor rods failed (one fractured, and one stripped the threads).
Pushover Results of the Tower Without Anchor Rods

- Yielding of Shear Links
- Yielding of More Shear Links
- Local Buckling at the Base of the Tower

(a) At Yield (Point Y)
(b) at Max. Strength (Point U)
(c) at Point where Ductility is Measured (Point D)
The retrofit measure suggested to mitigate the seismic hazard posed by the fracture of the hydrogen-embrittled tower anchor rods is to strengthen and stiffen the base of the tower.

(a) Yielding of the Base Plate

(b) Crushing of the Concrete under the Base Plate
The entire problem of hydrogen embrittlement of the anchor rods could have been avoided if instead of hot-dip galvanizing, other methods of galvanizing were used.

Or, instead of using A354 BD anchor rods, they had used slightly larger diameter A354 BC anchor rods that are allowed to be hot-dip galvanized.

Better yet, the A354 BC anchor rods could be made “upset” by making the area of unthreaded shaft smaller than the area of the threaded ends forcing the yielding of the reduced area of the shaft to be the governing ductile failure mode over the brittle fracture of the threaded areas.
C. The Behavior of the Pile Under Pushover Loads
Equivalent von Mises stresses

Stresses in the Steel Plates
Conclusions

1. The plates on the compression side of the tower shafts could locally buckle, which is an unacceptable performance.

2. Retrofit measures are suggested to prevent local buckling.

4. The hot-dip zinc galvanizing of the anchor rods, which is not allowed by the bridge specifications, has caused them to become hydrogen-embrittled and susceptible to fracture during the service life of the bridge or during a future seismic event.

5. Already 34 anchor rods, with two at the base of the tower, have fractured since 2013. This study shows that if more anchor rods were to fracture, prior or during a major earthquake, it is likely that the base of the tower shaft under compression will buckle locally.

6. Retrofit measures are suggested to strengthen and stiffen the base of the tower to mitigate these undesirable failure modes.

7. This investigation showed that there is a high risk of the fracture of the PJP (Partial Joint Penetration) welds connecting the composite piles to the composite pile cap during a major earthquake. Stress corrosion in the seawater during the 150 years design life of the bridge would increase the risk of fracture of these welds.