# Memorandum

**To:** CHAIR AND COMMISSIONERS

**CTC Meeting:** May 7, 2013

**Reference No.:** 3.7
Information

**From:** ANDRE BOUTROS
Executive Director

**Subject:** **San Francisco Bay Area Toll Bridge Seismic Retrofit 2013 First Quarter Project Progress and Financial Update**

**Summary:** Since the last Quarterly Report update, the following San Francisco Oakland Bay Bridge (SFOBB) Seismic Retrofit project construction and Toll Bridge Program Oversight Committee (TBPOC) activities occurred:

SFOBB East Span
Self Anchored Suspension (SAS) contract –

- On March 1, 2013, the contractor began stressing the anchor rods at the base of shear key S-1 and S-2 at the top of the E-2 pier. Shear keys are seismic elements designed to provide lateral restraint during an earthquake event. On the SAS, the lateral restraint is provided by a combination of four isolation bearings and four shear keys. This system is fastened to the top of the E-2 pier by 3 inch diameter anchor rods, for a total of 288 anchor rods. The first 98 anchor rods were manufactured in 2008 and the remaining 192 anchor rods were manufactured in 2010.
- Between March 8 and March 15, thirty two of the ninety eight 2008 anchor rods fractured. The contractor immediately de-tensioned the remaining 2008 rods and began working with the department on a parallel path of forensic analysis to determine why the 2008 rods failed and on an alternative attachment system for the two shear keys where the rods failed. The 2008 rods are permanently imbedded in the E-2 pier and cannot be removed and replaced.
- Forensic analysis indicates hydrogen entered the steel rods and caused what is known as hydrogen embrittlement. Hydrogen embrittlement is caused by hydrogen in combination with stress, either externally applied or internal residual stress. Hydrogen embrittlement can have two causes Internal Hydrogen Embrittlement (IHE) where residual hydrogen remains in the steel after processing (including pickling and electroplating) and Environmental Hydrogen Embrittlement (EHE) where hydrogen from an external source, e.g. hydrogen rich environment (standing water) is absorbed into the steel through Stress Corrosion Cracking (SCC) or through Cathodic Hydrogen Absorption (CHA). Either IHE or EHE alone or both in combination with each other can cause hydrogen embrittlement failure. We don't know if the hydrogen was introduced during rod fabrication (IHE) or after installation (EHE) or if it was externally applied stress (tensioning of the rods) or internal residual stress that caused the failure, but we do know it was hydrogen in the steel that caused the failure. More analysis is being done to determine the actual failure path.
- As stated above, the contractor, the department and the bridge design team is working on alternative attachment system design solutions for shear keys S-1 and S-2. As of April 17, 2013, the design alternatives have been narrowed down from about four or five to two. A steel collar

where a metal frame grillage would be added around the shear key base to hold it down that is at about a 45% design stage and a pre stressed collar made from post tensioning (PT) strands and concrete that is at about a 30% design stage. Once the designs are at about 65% design the TBPOC will decide which alternative will go to 100% design, fabrication and installation. The decision should be made before or in time for the May 7 CTC meeting.

- The 2010 rods are not imbedded in the E-2 pier and can be replaced if necessary. The TBPOC decided to test the 2010 rods in–site. All 192 rods were fully stressed and ten rods have been instrumented. The instrumented rods will be removed and will undergo destructive testing to determine their mechanical and physical properties. Two rods were removed for early destructive testing on April 20, 2013, an additional two rods will be removed for early destructive testing and the other six rods will be removed and tested after 30 days of stress. So far none of the 2010 rods have failed. After the destructive testing is completed the TBPOC will determine if the 2010 rods will remain in place or will be replaced.
- The TBPOC is fully engaged and in addition decided that all findings and decisions relative to the pier E-2 rods will be publically communicated at the Bay Area Toll Authority (BATA) regularly scheduled oversight committee and full board meetings and of course CTC meetings as they occur.

**Background:** In July 2005, Assembly Bill 144, (AB144) Hancock created the Toll Bridge Program Oversight Committee (TBPOC) to exercise project oversight and control over the Toll Bridge Seismic Retrofit Program. The TBPOC is comprised of the Director of the Department of Transportation (Caltrans), the Executive Director of the Bay Area Toll Authority (BATA), and the Executive Director of the California Transportation Commission (CTC). The TBPOC's program oversight and control activities include, review and approval of contract bid documents, contract change orders and resolution of major project issues.

# Briefing on E2 Anchor Bolts – May 7, 2013

# Toll Bridge Program Oversight Committee

- **AB 144 established the *Toll Bridge Program Oversight Committee*, composed of Director of the California Department of Transportation (Caltrans), and the Executive Directors of the California Transportation Commission (CTC) and the Bay Area Toll Authority (BATA), to be accountable for delivering the Seismic Retrofit Program.**

MALCOLM DOUGHERTY
Director
California Department of Transportation

STEVE HEMINGER
Executive Director
Bay Area Toll Authority

ANDRE BOUTROS
Executive Director
California Transportation Commission

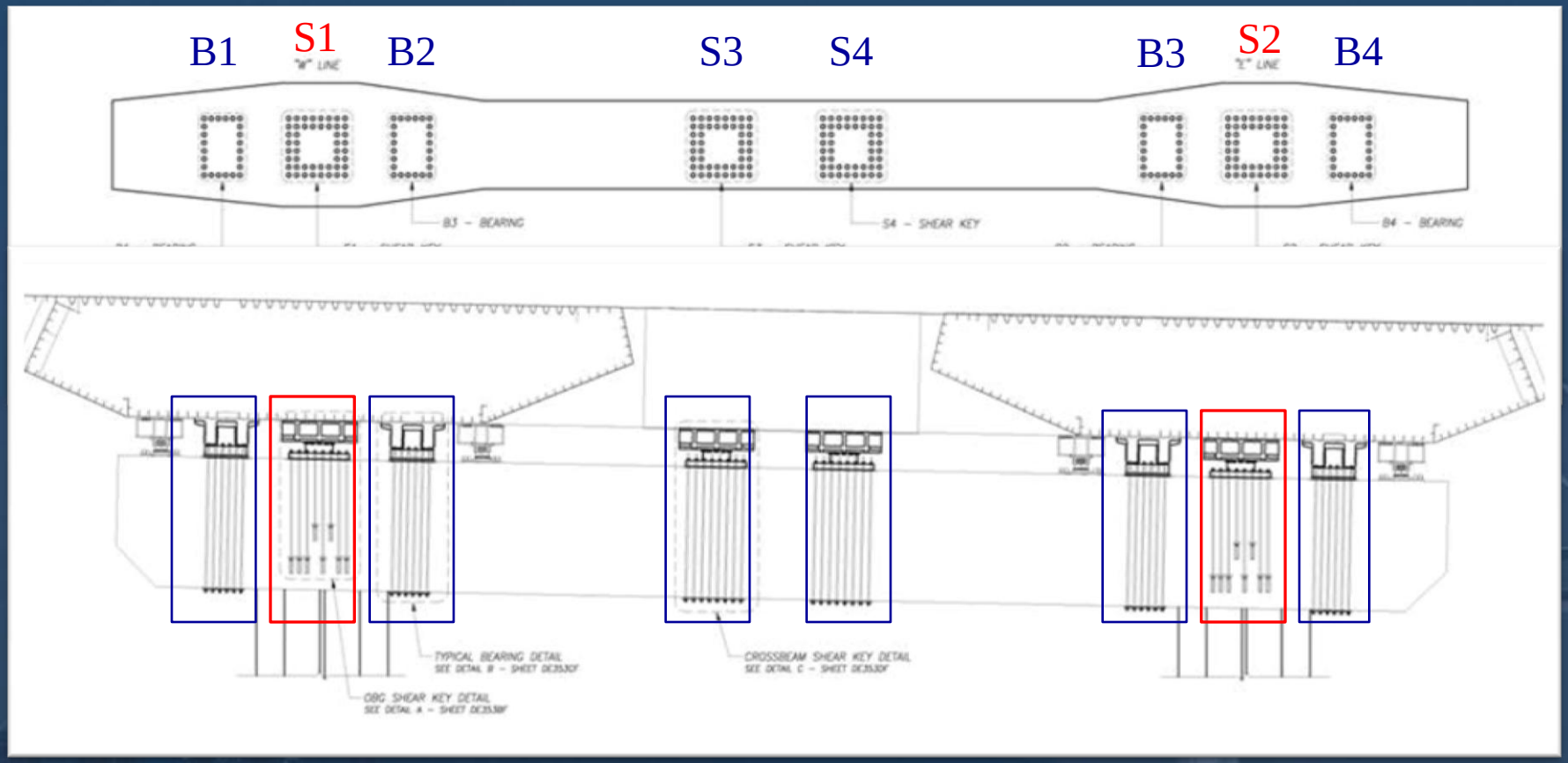
# Three Key Questions

1. What caused the E2 anchor bolts manufactured in 2008 to fail?

2. What retrofit strategy should be used to replace the 2008 anchor bolts?

3. Should the anchor bolts manufactured in 2010 be replaced?


Pier E2




- **Bearings and shear keys are secured to E2 by 3 inch diameter anchor bolts, ranging from 9 feet to 24 feet in length.**
- **96 bolts manufactured in 2008 shown in red are embedded in the pier.**
- **192 bolts manufactured in 2010 shown in blue are <u>not</u> embedded in pier.**

# 1. What caused the E2 anchor bolts manufactured in 2008 to fail?

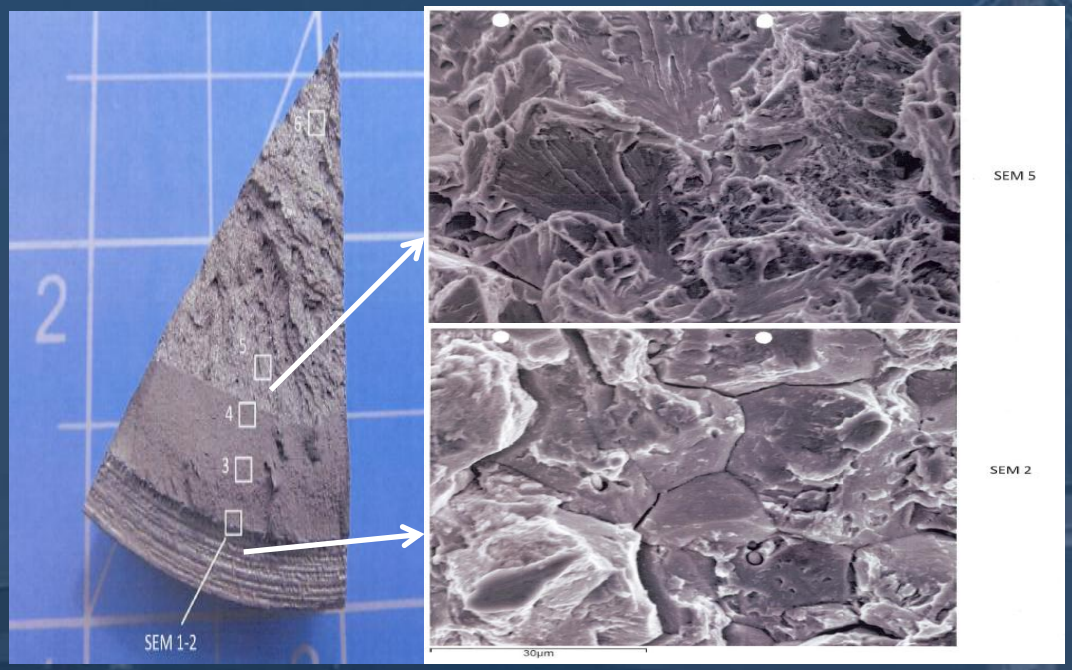
# Failure of 2008 Bolts Due to Hydrogen Embrittlement

- Under detailed investigation, 2008 bolt failures are due to hydrogen embrittlement.
- Excess hydrogen in the 2008 bolts caused the threaded areas of bolts to become brittle and fracture under high tension.

# Hydrogen Embrittlement

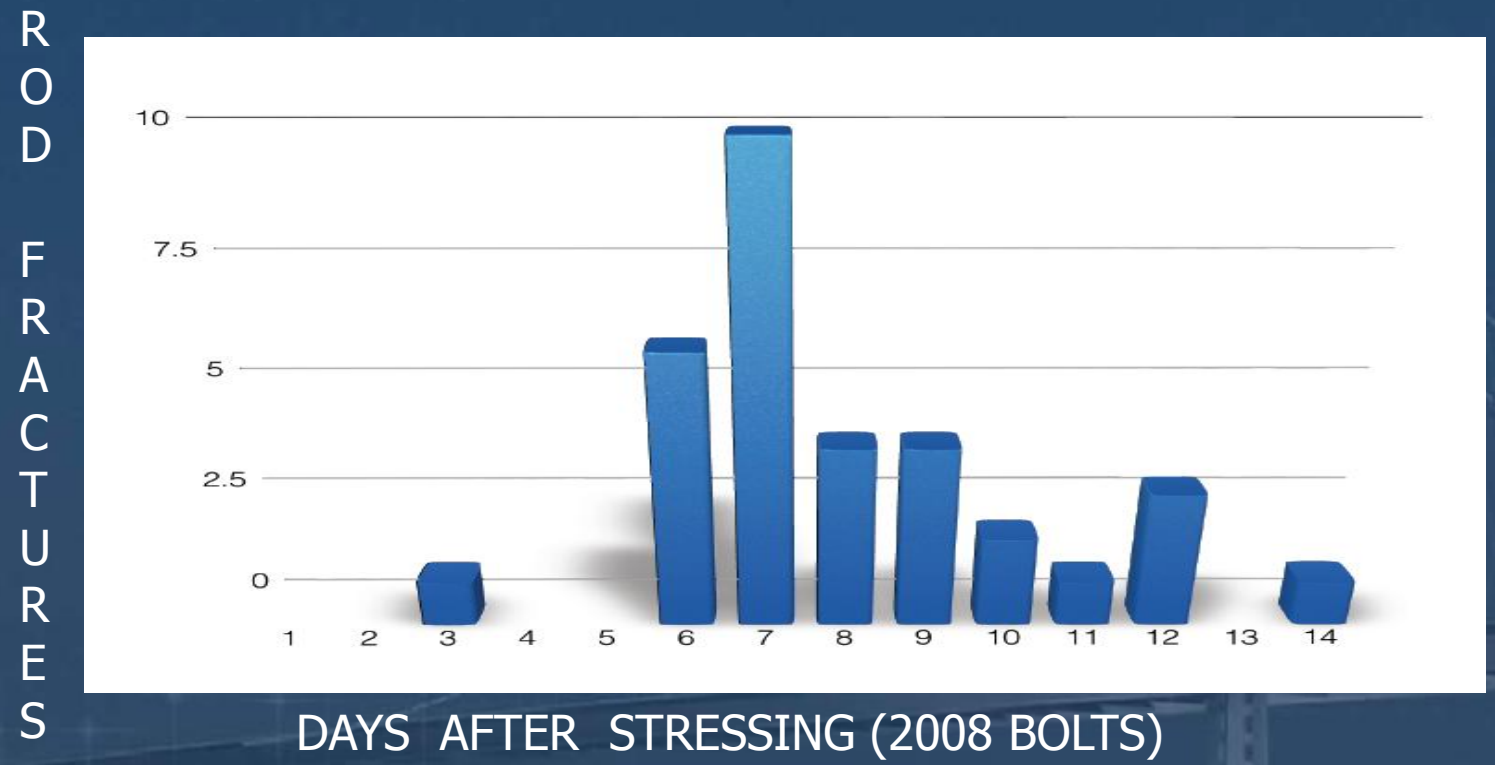
- **Requires 3 elements**
  - **Source of Hydrogen**
  - **Susceptible Material**
  - **Tension**
- **Sources of excess hydrogen may have been both internal (residual from production) and/or external.**

# Hydrogen Embrittlement




1000X Magnification

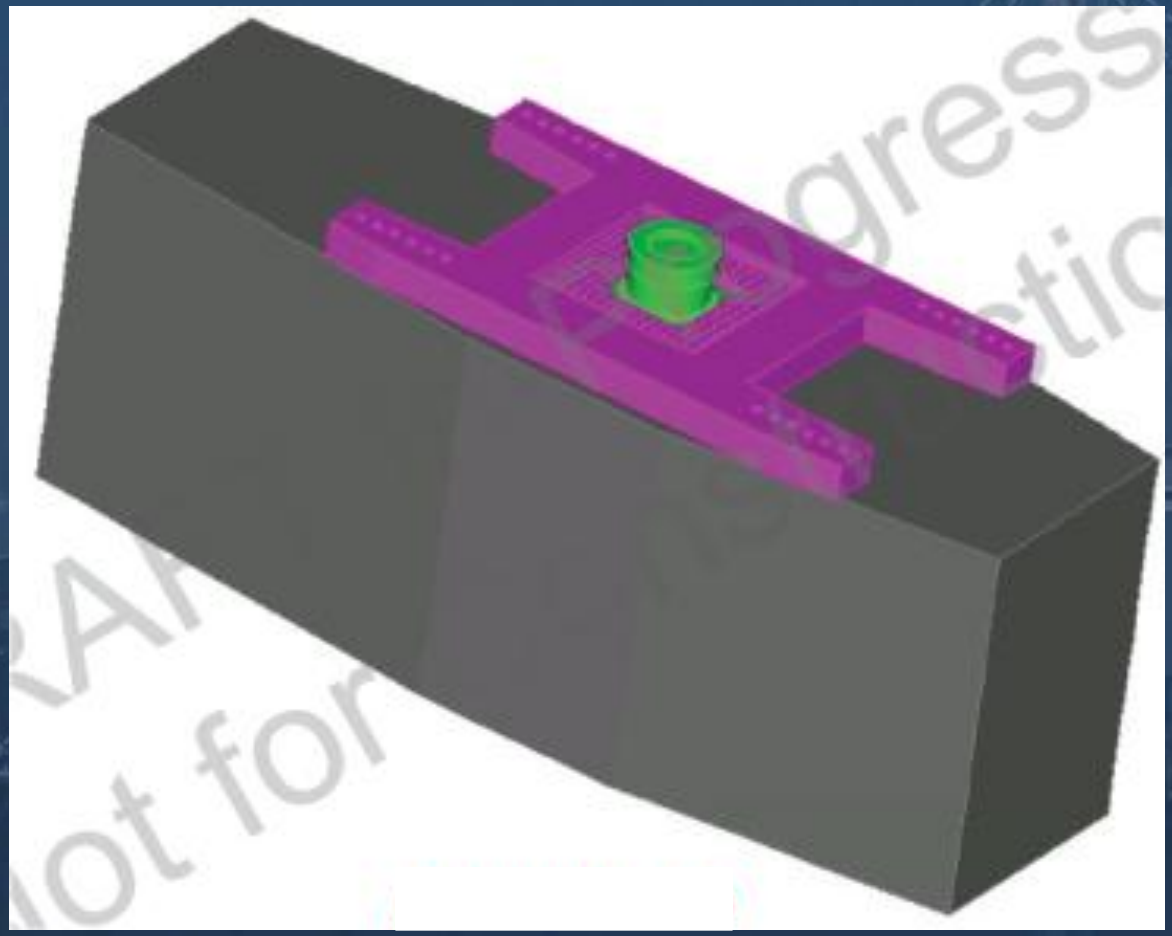
- On-going metallurgical analysis indicates 2008 bolts were susceptible to hydrogen embrittlement due to "a lack of uniformity in the microstructure of the steel"
- Identified under electron microscope.




- Failure by hydrogen embrittlement is time dependent and should happen within weeks of tensioning.
- 2008 bolts failed days after tensioning. After 14 days, all 2008 bolts were de-tensioned.
- Industry standard testing protocols for A354 bolts are not time-dependent. Lesson learned: Additional material specifications and testing protocols could have reduced risk of hydrogen embrittlement.

# 2. What retrofit strategy should be used to replace the 2008 anchor bolts?

# Option 1 – Steel Collar



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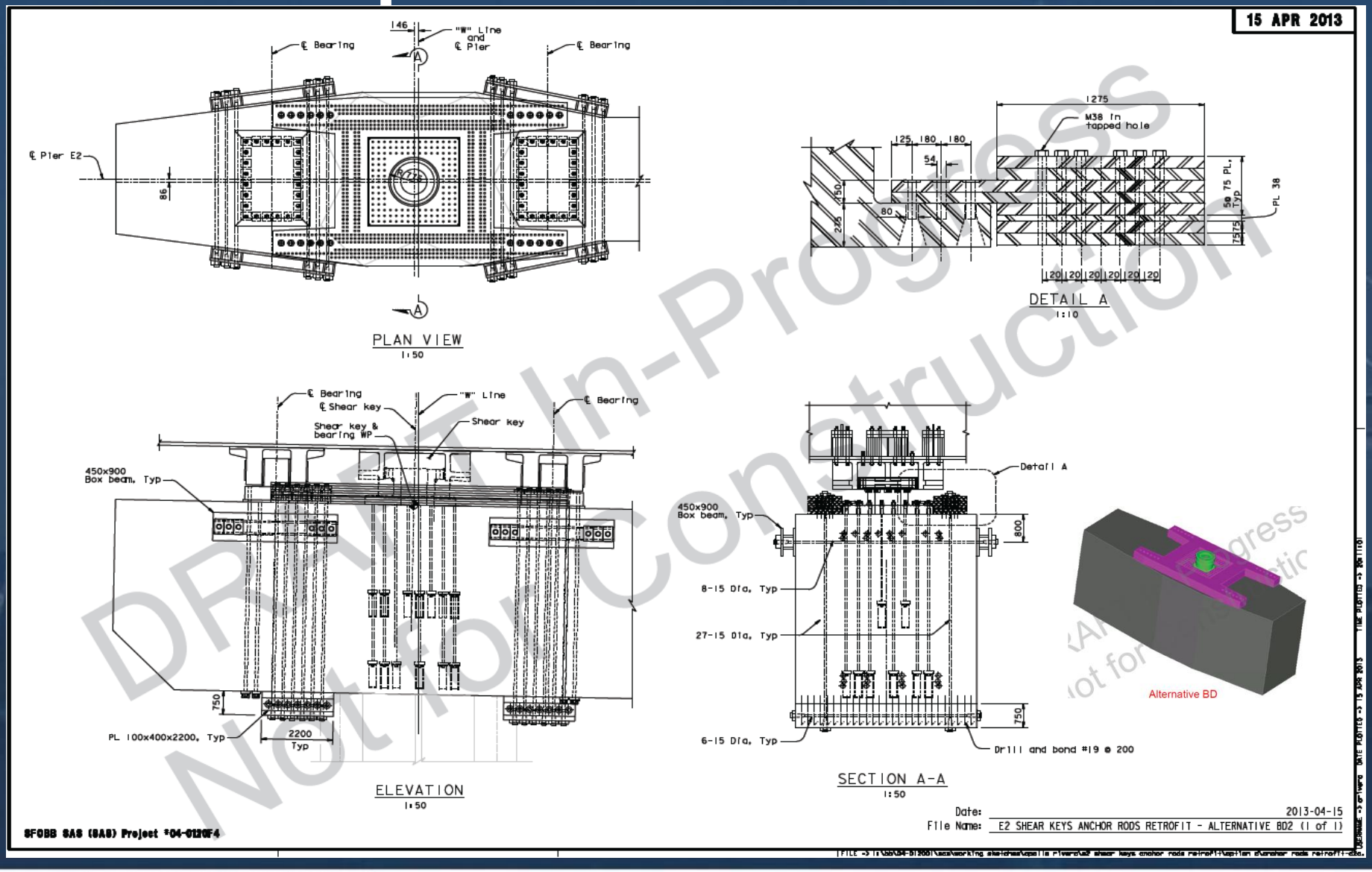

# Option 2 – Steel Saddle

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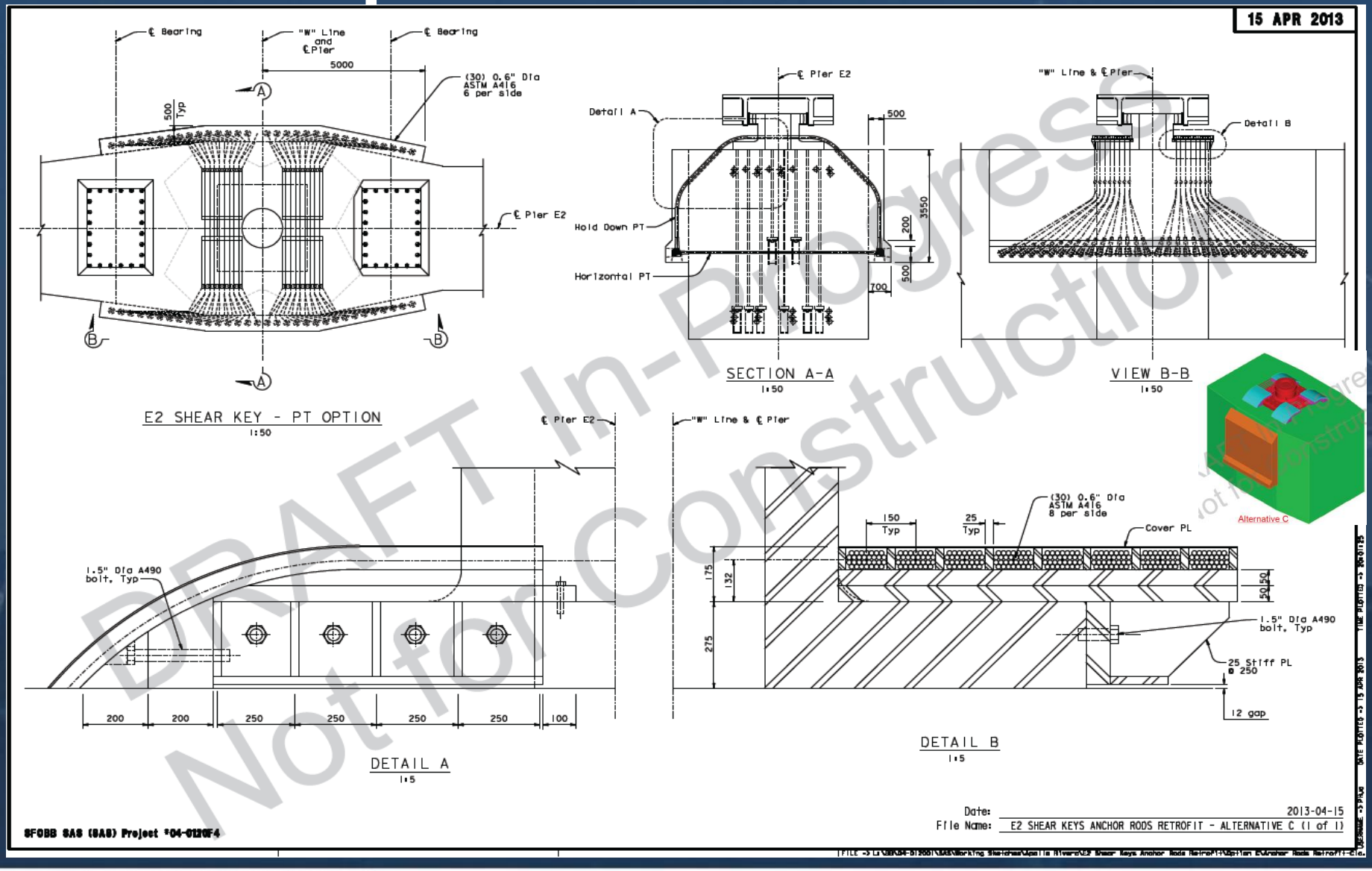


# Additional Information

- Contractor already has placed steel order for both design options.

- Contractor already has selected local fabricator on Mare Island.

# 3. Should the anchor bolts manufactured in 2010 be replaced?

# Differences

- After 20 to 30 days under tension, none of the 2010 bolts have failed.
- 2008 and 2010 bolts were manufactured 2 years apart using different batches of steel.
- There were fewer material batches used in the 2010 bolts and less variation on the mechanical properties.
- 2010 bolts are not embedded in E2 pier cap.
- Ongoing metallurgical analysis may reveal important additional differences.

# Similarities

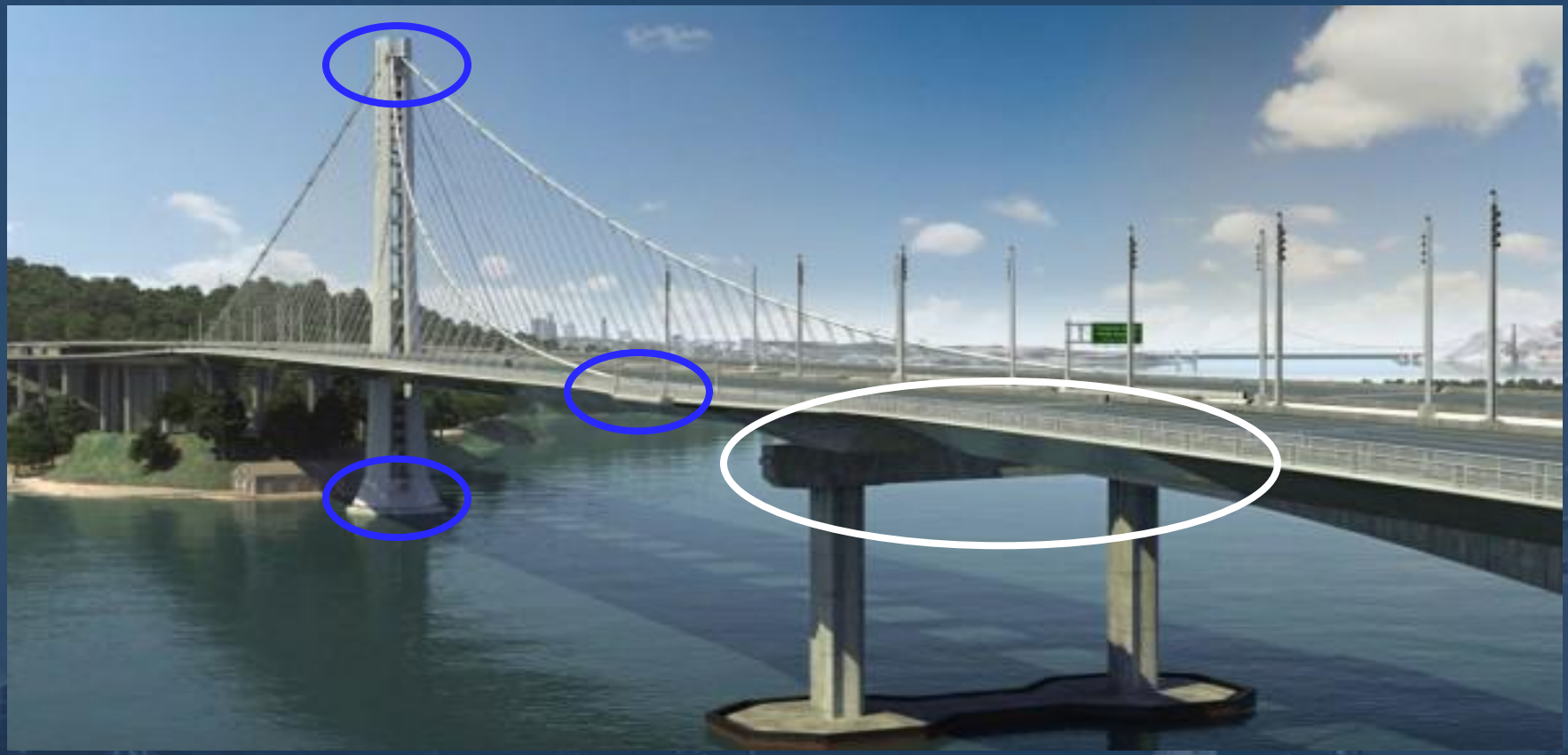
- Both 2008 and 2010 bolts originated from same principal supplier.
- Both sets of bolts were manufactured to the same specifications, including galvanizing.
- Both sets of bolts have been tightened to the same relatively high tension level.
- Both sets of bolts exhibit similar mechanical properties, but the 2010 bolts are marginally more ductile.
  (see next slide)

# Post-Heat Treatment QC/QA Mechanical Tests

| | Tensile (KSI) | Yield (KSI) | Elongation (%) | Reduction of Area (ROA) | Hardness (Rockwell C) |
|---|---|---|---|---|---|
| ASTM A354BD | 140 | 115 | 14 | 40 | 31-39 |
| 2008 Average | 164 | 142 | 14.3 | 48.4 | 36.8 |
| 2008 Min/Max | 152/173 | 127/158 | 12.5/16.2 | 40/50 | 33/37 |
| 2010 Average | 159 | 139 | 15.5 | 50.5 | 34.1 |
| 2010 Min/Max | 153/165 | 132/147 | 13.2/17.1 | 40/55 | 32/37 |

# Testing Protocol for 2010 Bolts

- **Current Contract Required Testing**
  - Tensile
  - Yield
  - Elongation
  - Reduction of Area
  - Hardness
- **New Additional Testing**
  - Tensioning bolts in-situ to required load for 30 days to allow time-dependent migration of hydrogen.
  - Tensile test of an extracted full-size bolt through to fracture.
  - Toughness and Chemical Analysis
  - Microscopic examination by electron microscope
  - Micro-Structural examination to determine presence of hydrogen.



- Visual inspections of similar anchor bolts revealed no abnormalities.
- Some E2 Bearing assembly bolts are not accessible to inspection.
- Most anchor bolts at other locations are under lower tension levels.
- Prioritized Desk Audit of QC/QA results underway.

# Summary

- Failure of 2008 bolts was the result of hydrogen embrittlement.
- Two retrofit alternatives are still being evaluated.
- 2010 bolts are being tested with revised protocols.
- Prioritized desk audit of QA/QC results for similar bolts by same manufacturer underway. Findings will be made available as completed.

# Expected at May 8th BATA Briefing

- Selection of 2008 bolt retrofit solution, including cost and schedule impacts.
- Pending results from initial testing of 2010 bolts, decision on whether to replace 2010 bolts and, if so, when.
- Completion of desk review of additional QA/QC results for other high tension anchor bolt locations.