

Briefing on E2 Anchor Bolts – April 24, 2013



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY CALIFORNIA TRANSPORTATION COMMISSION

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



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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?



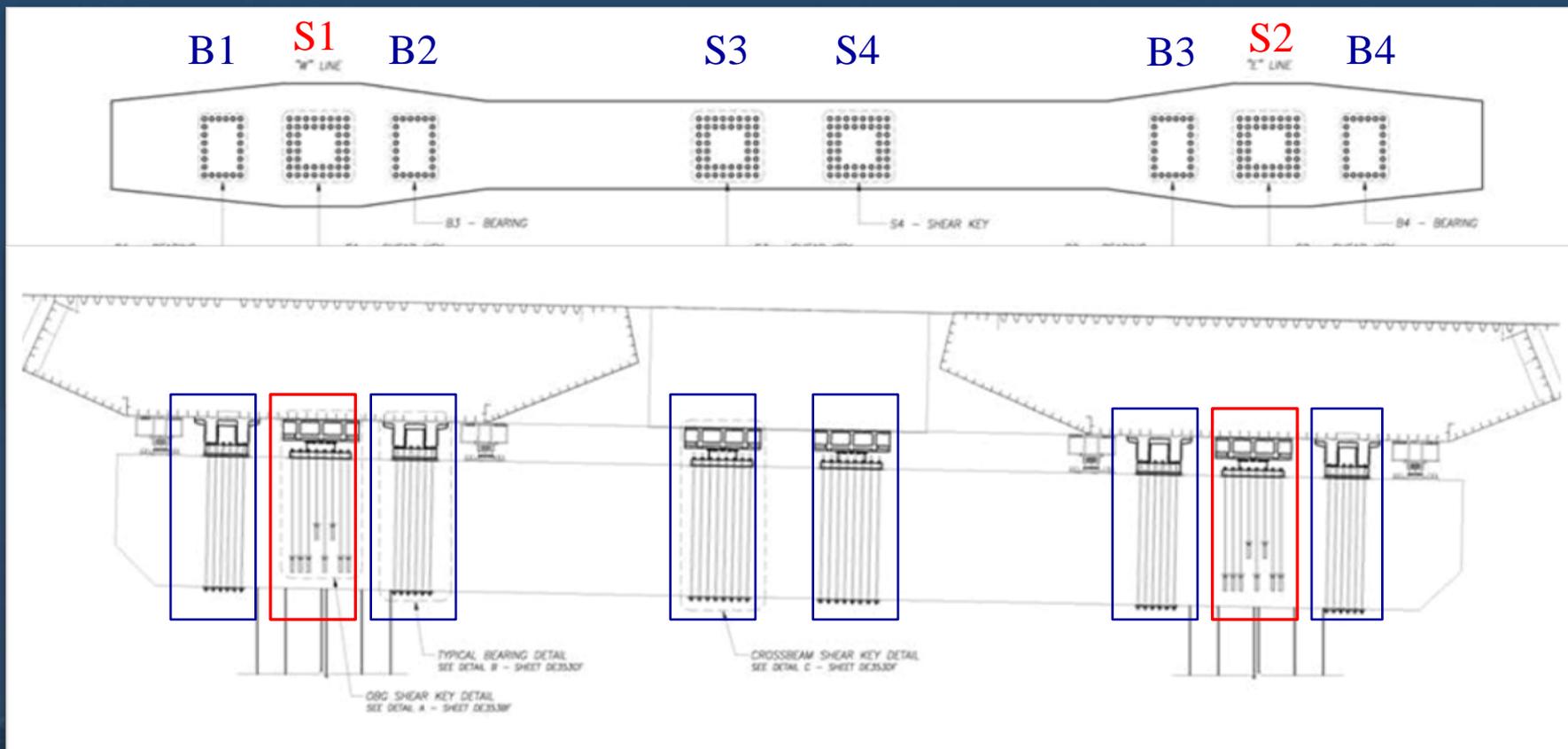


Pier E2



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- 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 not 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.

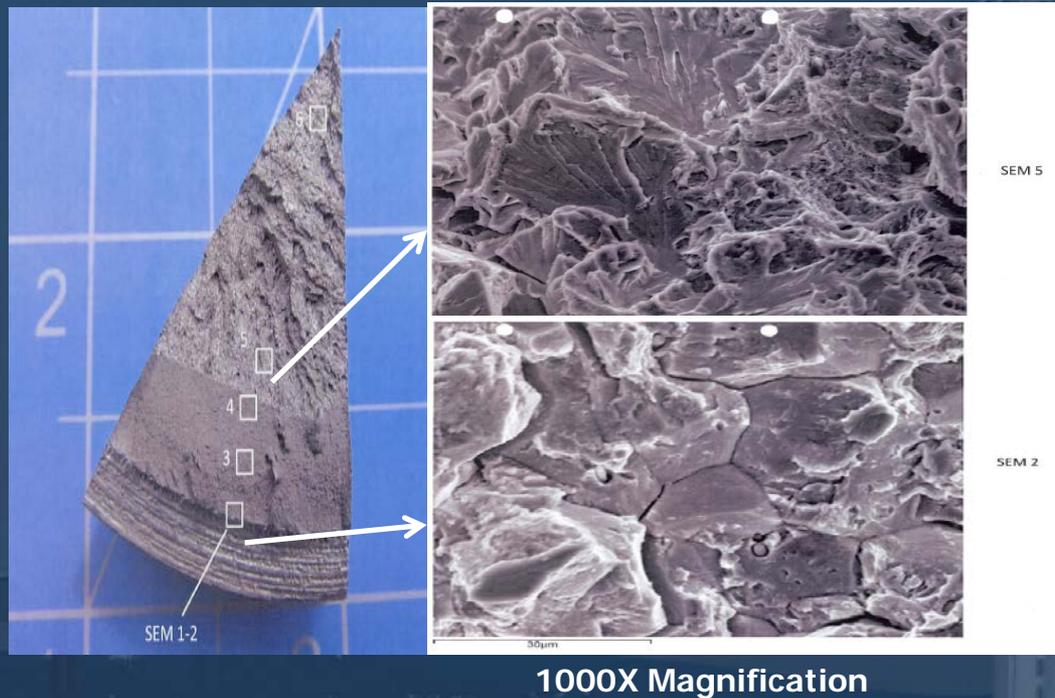


Hydrogen Embrittlement

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

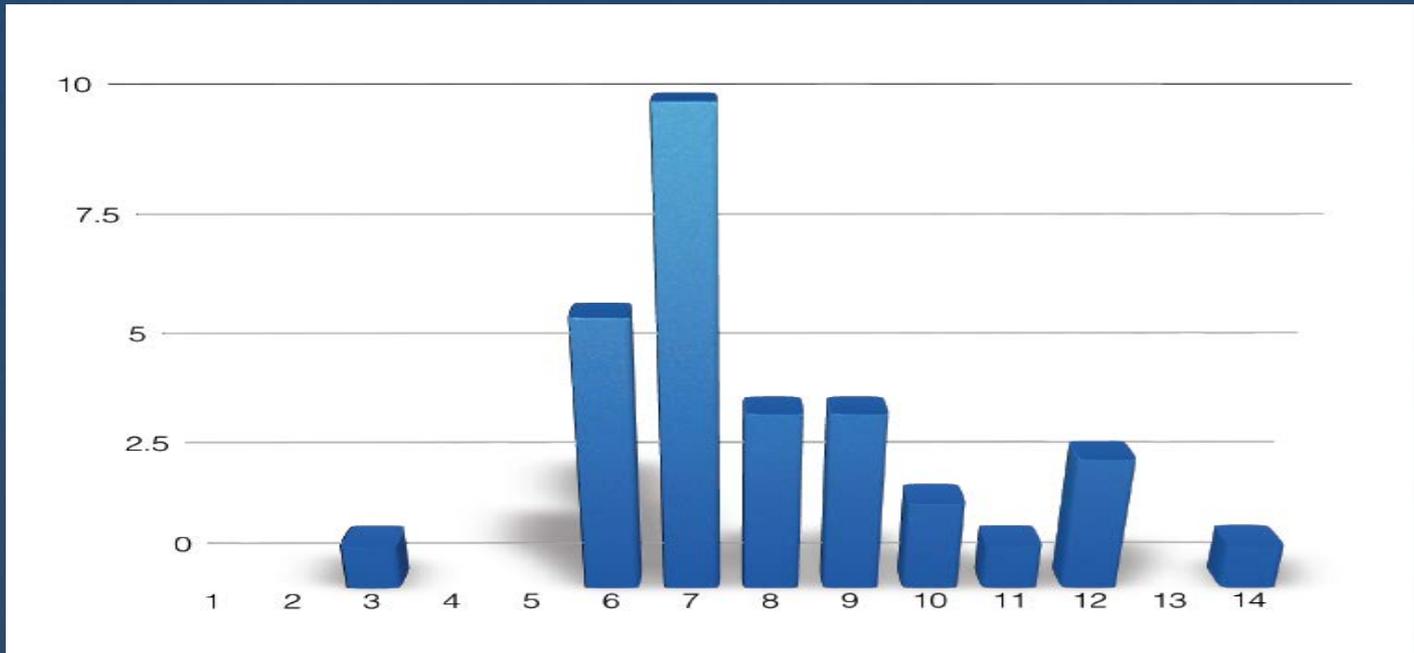


Hydrogen Embrittlement



- 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.





DAYS AFTER STRESSING (2008 BOLTS)

- 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.

Other Issues

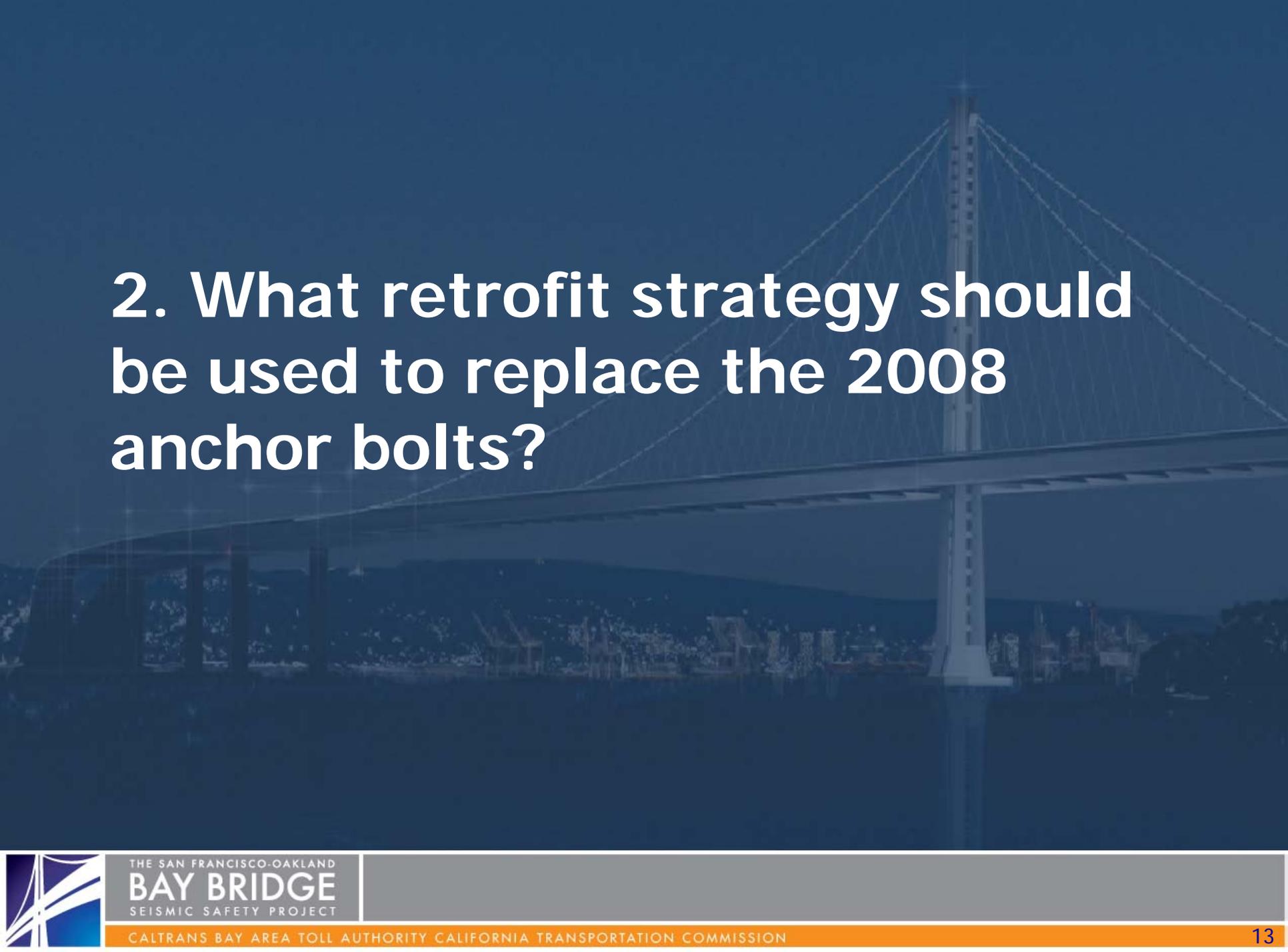
Issue	Response
Documentation	All facilities involved in fabrication of the bolts received complete and unqualified “passes” from the Caltrans’ Quality Assurance (QA) audit of the facilities. Some facilities received initial “contingent passes”, which were followed by submission and review of additional information that adequately addressed contingencies. A final pass was given to all facilities.
Second Heat Treatment	It is not unusual for bolts to receive two heat treatments. The two heat treatments for the 2008 bolts did not result in additional susceptibility to hydrogen embrittlement.
Galvanization	Bolts are galvanized for long-term corrosion protection. Galvanization is allowed but cautioned in ASTM specifications; associated hydrogen embrittlement risks are addressed through elimination of pickling, as outlined by ASTM specifications.



Other Issues

Issue	Response
Bolts Ordered Late	Although bolts were ordered on an accelerated basis, there was no reduction in quality control/quality assurance (QC/QA) measures taken.
Magnetic Particle Testing	The application (or lack) of magnetic particle testing (MT) is not relevant to hydrogen embrittlement. MT is not a mandatory ASTM requirement for these bolts. MT is related to identification of surface anomalies, and not associated with detection of hydrogen embrittlement.
Embedment of Bolts	Since bolt installation in 2008, staff noted that moisture was found in some of the bolt holes, which may have contributed to hydrogen contamination. Lesson Learned: Where feasible, tie-down elements this critical to seismic performances should be accessible to repair.

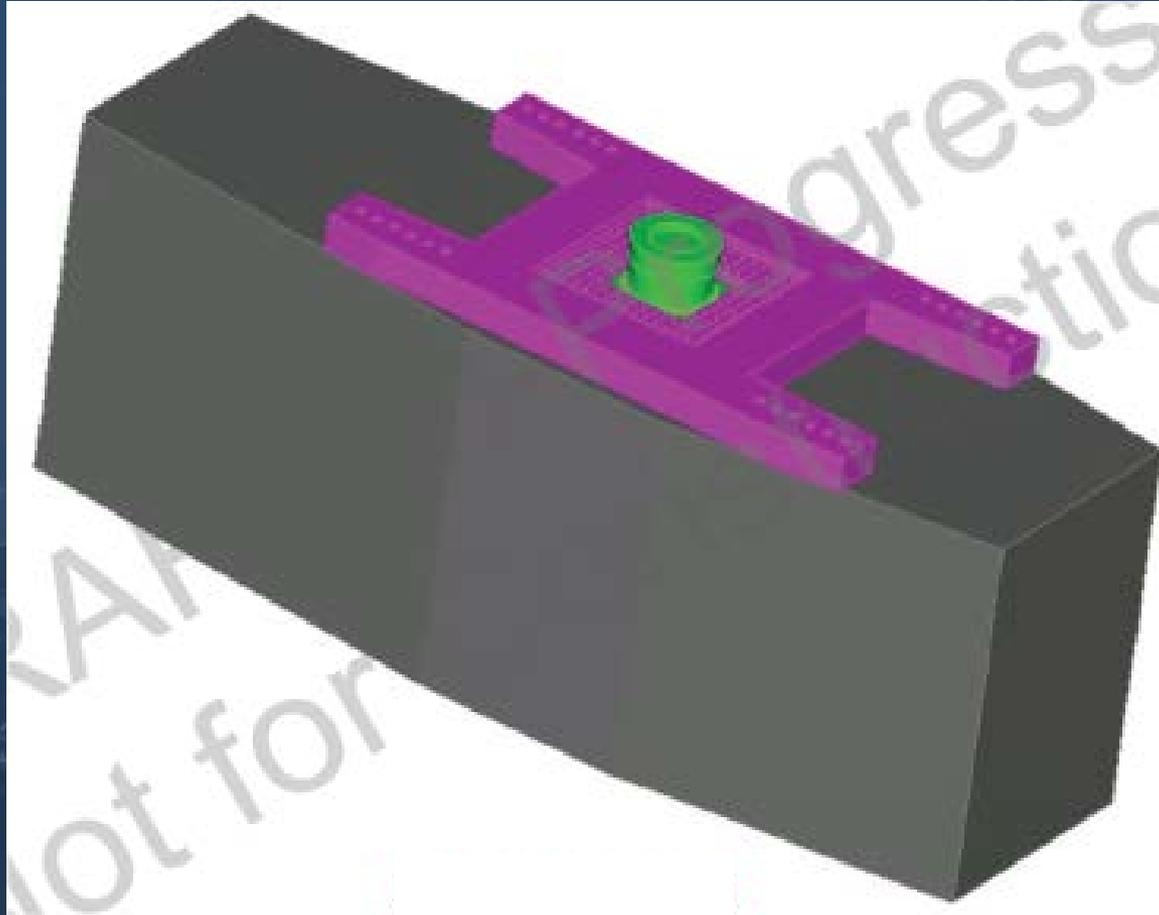




2. What retrofit strategy should be used to replace the 2008 anchor bolts?

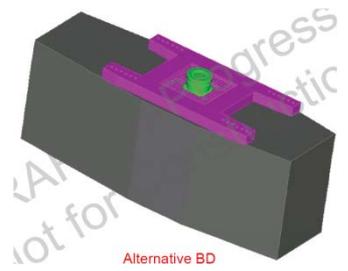
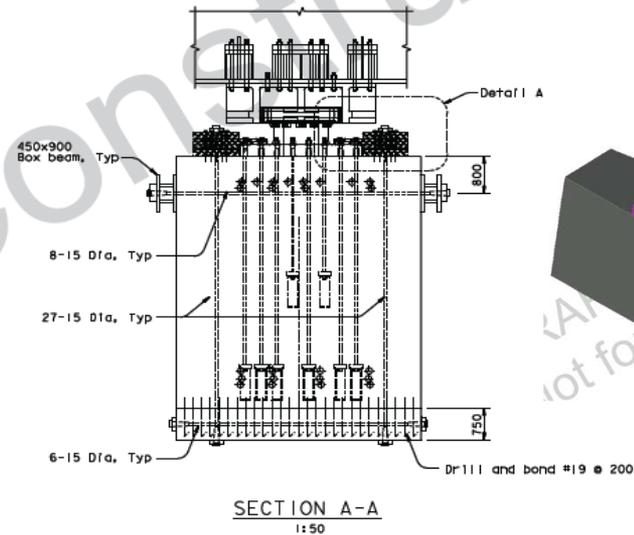
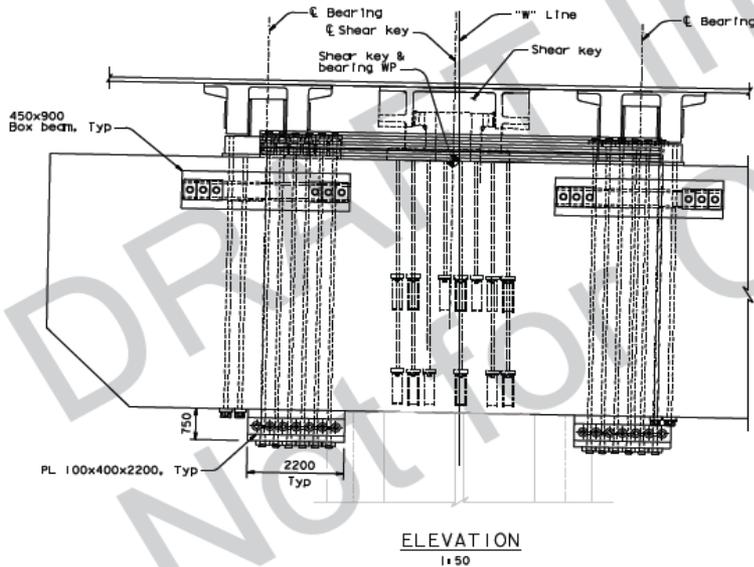
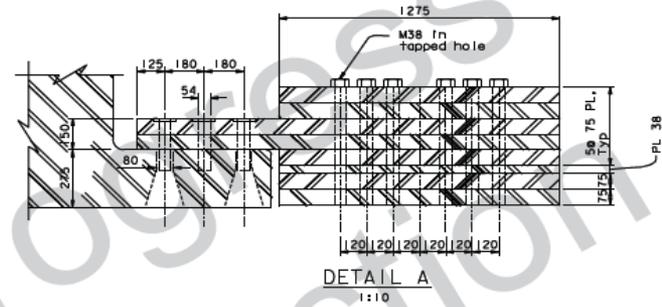
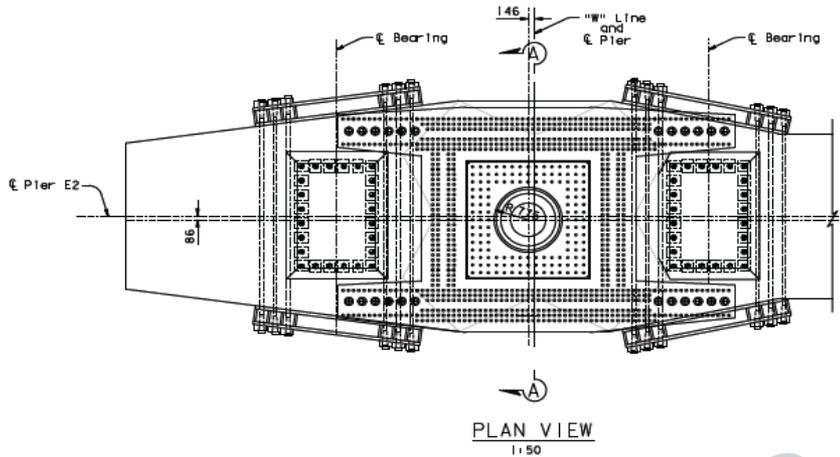


Option 1 – Steel Collar



Option 1 – Steel Collar

15 APR 2013



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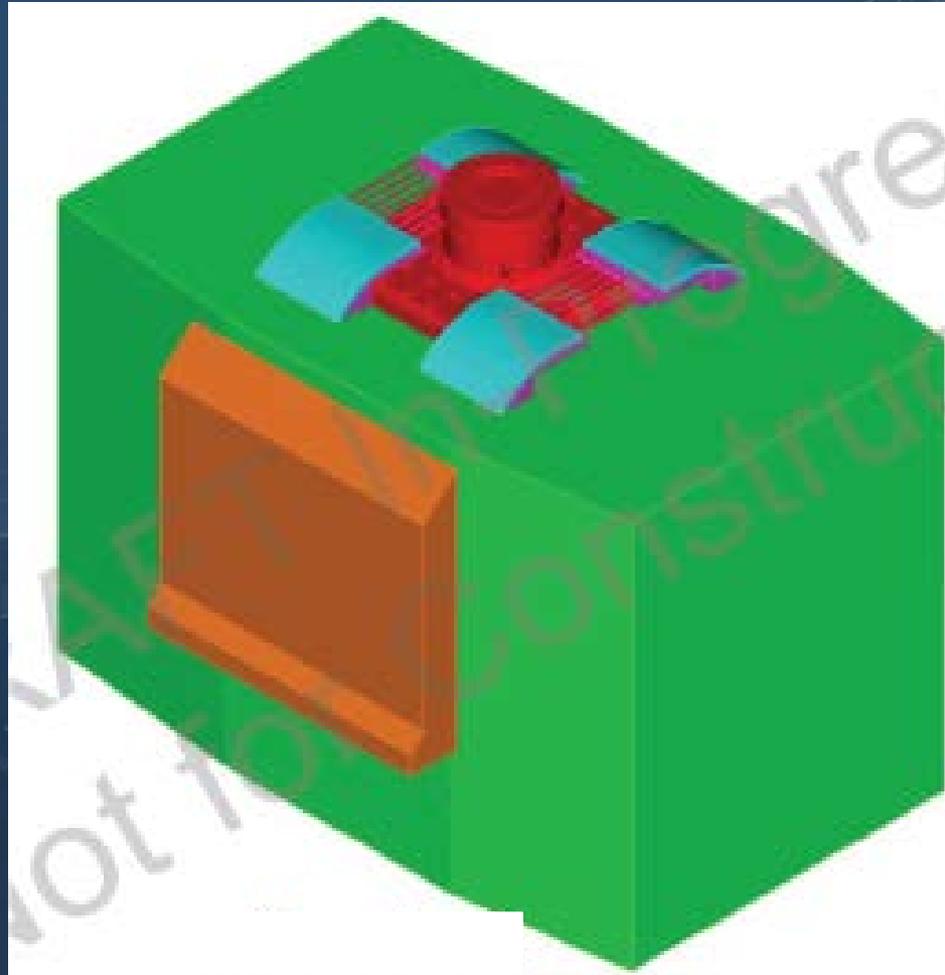
Date: 2013-04-15
File Name: E2 SHEAR KEYS ANCHOR RODS RETROFIT - ALTERNATIVE BD2 (1 of 1)



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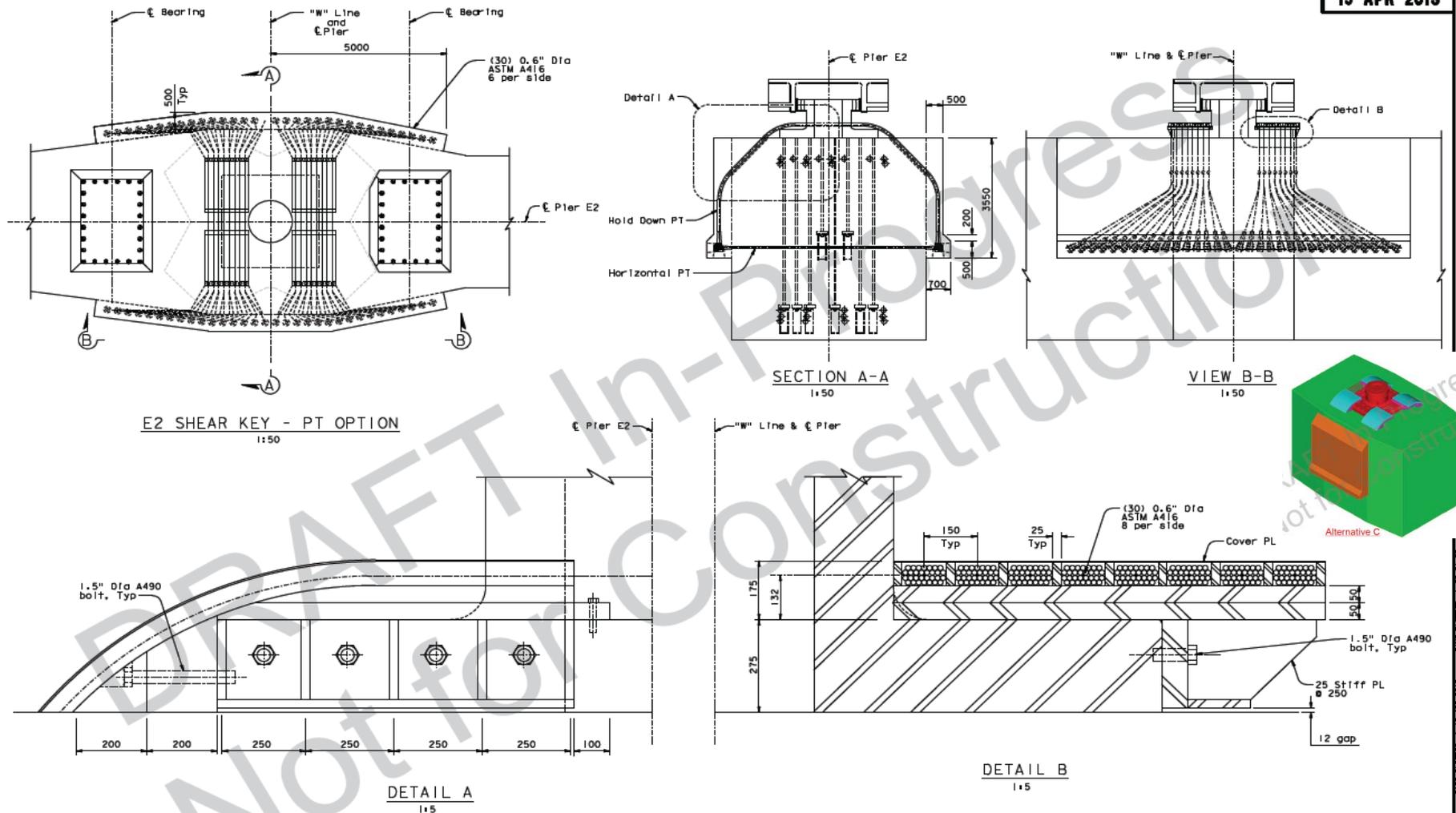
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Option 2 – Steel Saddle



Option 2 – Steel Saddle

15 APR 2013



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Date: 2013-04-15
 File Name: E2 SHEAR KEYS ANCHOR RODS RETROFIT - ALTERNATIVE C (1 of 1)



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General Comparison of Options

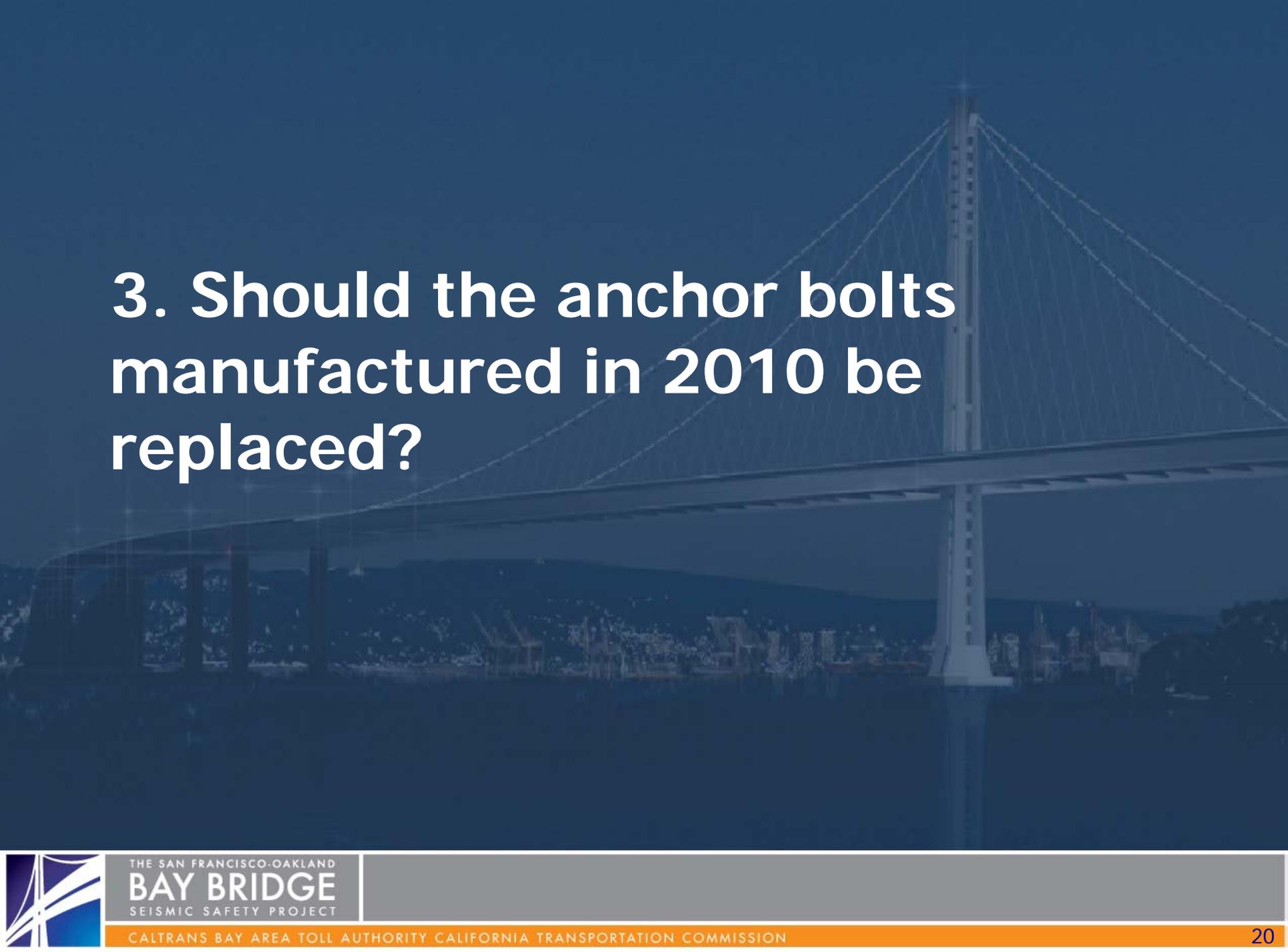
Option 1 – Steel Collar	Option 2 – Steel Saddle
<p>Pros</p> <ul style="list-style-type: none">• No need to remove S1 and S2 shear keys• Potentially simpler to fabricate	<p>Pros</p> <ul style="list-style-type: none">• No need to remove S1 and S2 shear keys• Less coring of E2 required
<p>Cons</p> <ul style="list-style-type: none">• Need to find sufficient materials and resources• More coring of E2 required	<p>Cons</p> <ul style="list-style-type: none">• Requires unique saddle system.



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 15 to 25 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

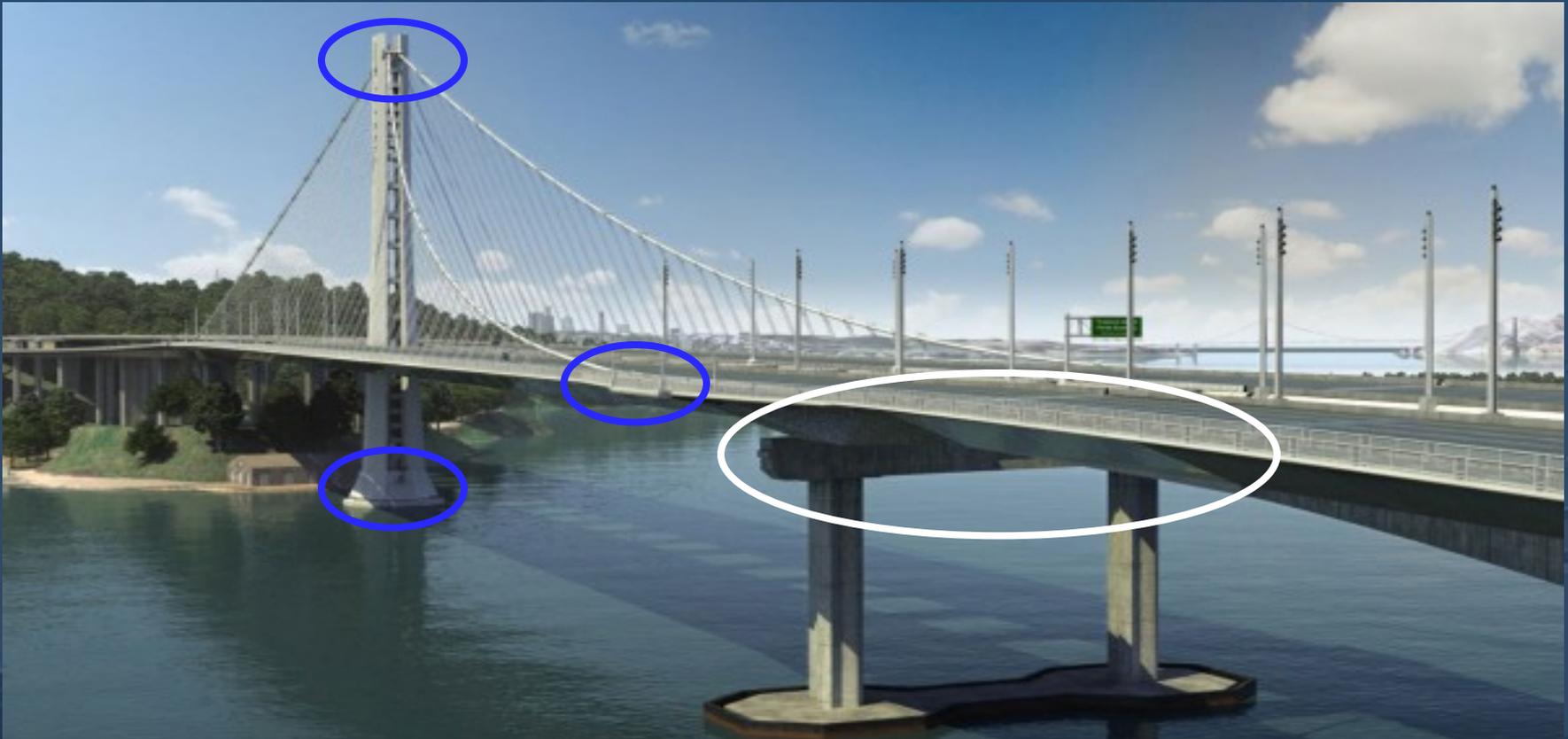
	Tensile (KSI)	Yield (KSI)	Elongation (%)	Reduction of Area (ROA)	Hardness (Rockwell C)
ASTM A354BD	140	115	14	40	31-39
2008 Average	164	142	14.3	48.4	36.8
2008 Min/Max	152/173	127/158	12.5/16.2	40/50	33/37
2010 Average	159	139	15.5	50.5	34.1
2010 Min/Max	153/165	132/147	13.2/17.1	40/55	32/37



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.



Items Expected at May 8th 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.

