Briefing on E2 Anchor Bolts – May 8, 2013

Four Key Questions

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

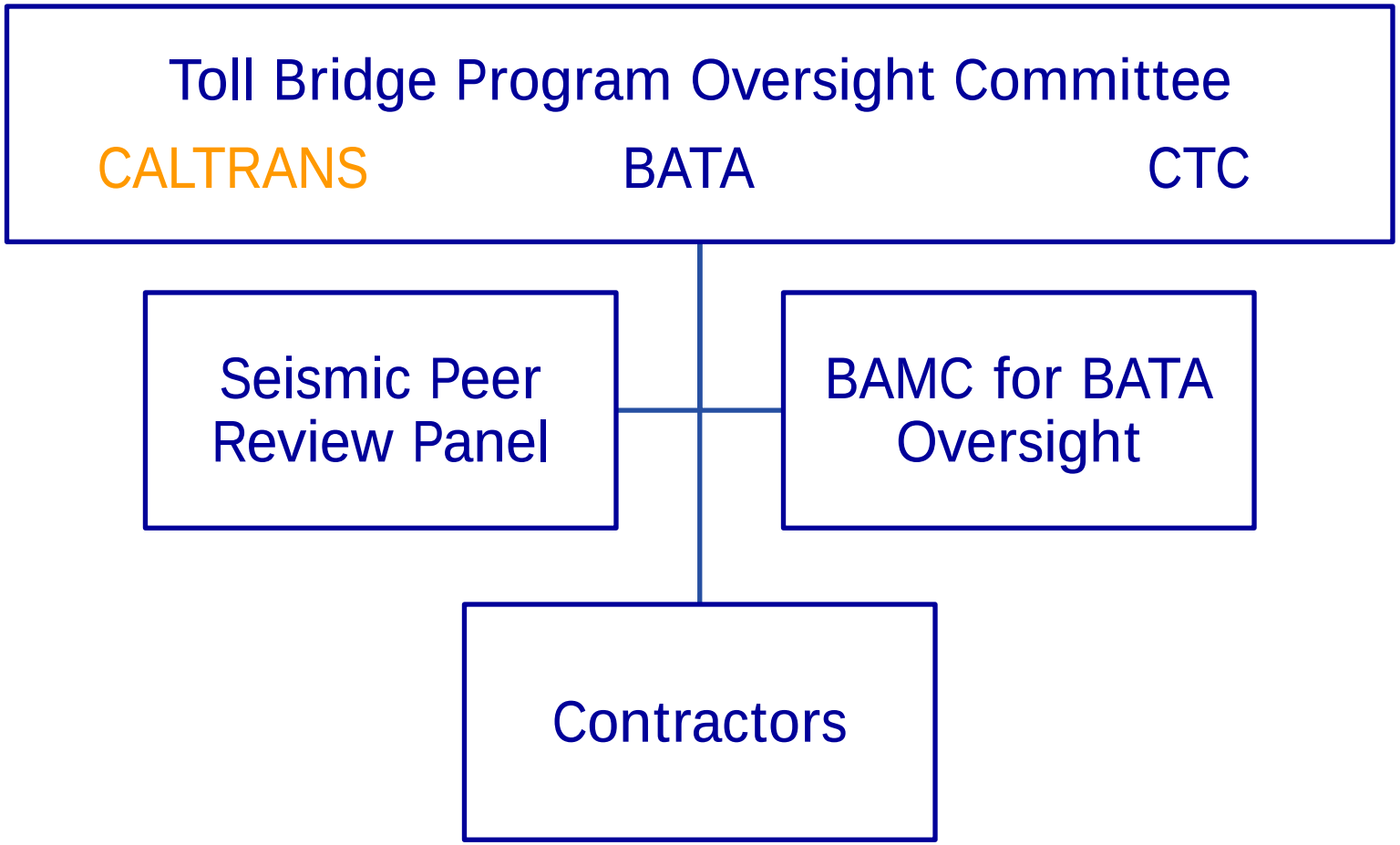
2. What retrofit strategy should be used to replace the 2008 anchor bolts?

3. Should the remaining bolts on the E2 pier manufactured in 2010 be replaced?

4. What should be done about other similar bolts on the SAS?


Pier E2

Oversight Structure



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

Toll Bridge Seismic Peer Review Panel

- Dr. Frieder Seible, Dean Emeritus of the Jacobs School of Engineering at the University of California at San Diego, has consulted on many of the world's long-span bridges and has extensively published related to seismic design and blast resistant design of critical structures.

- Dr. I.M. Idriss, Emeritus Professor of Civil Engineering at the University of California at Davis , is a Geotechnical Engineer who has performed follow-up analysis of every major earthquake since the 1964 Alaska quake and has been part of numerous engineering teams to analyze damage and determine causes of structural collapse.

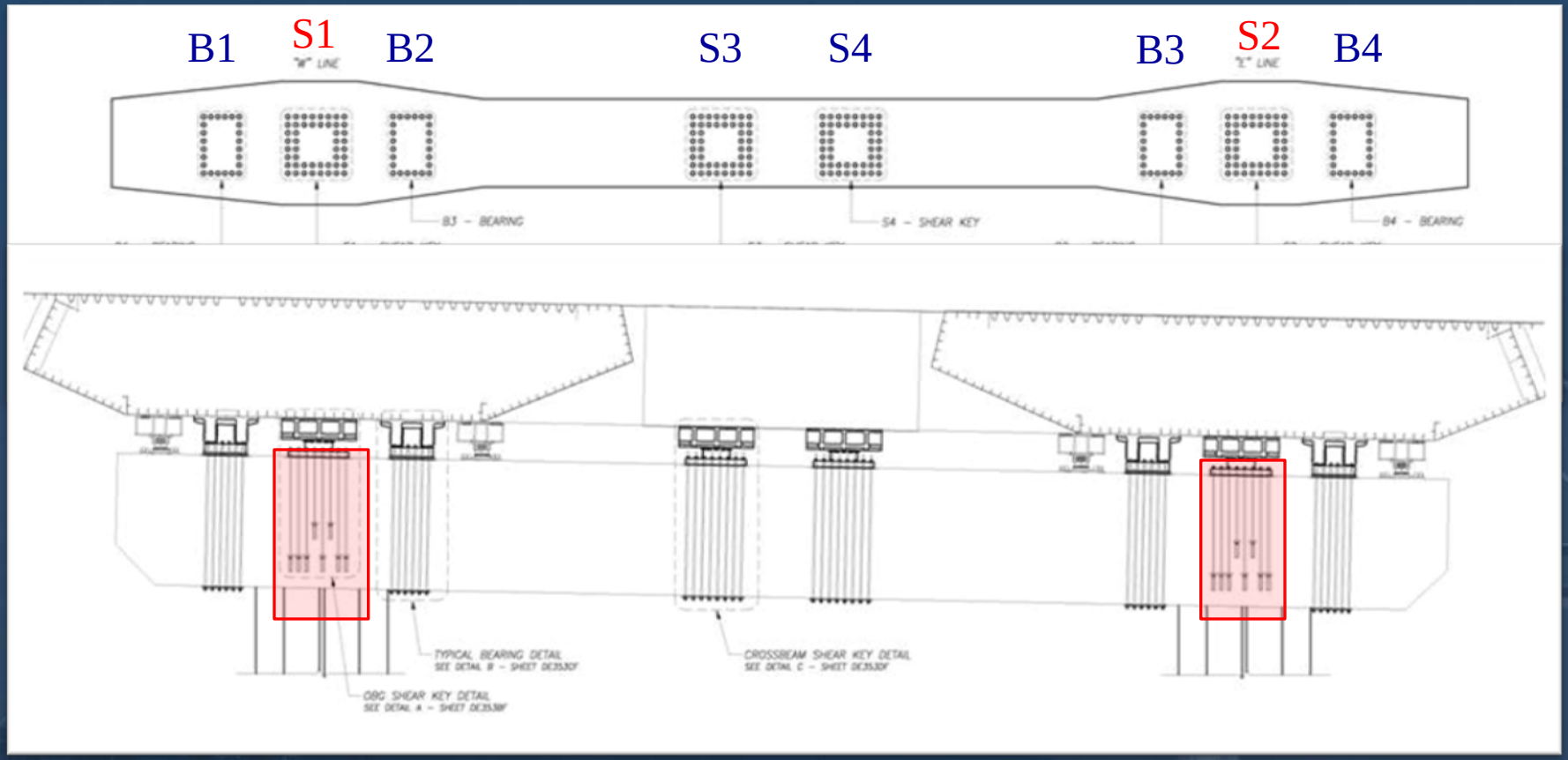
- Dr. John Fisher, Professor Emeritus of Civil Engineering at Lehigh University, has focused his research on the behavior and performance of steel bridges and has examined most of the major failures of steel structures in America throughout the last four decades, including the World Trade Center in 2001.

- All three are members of the National Academy of Engineering.

FHWA Independent Review

- **The TBPOC has requested that the Federal Highway Administration (FHWA) conduct an additional independent review of our findings and recommendations concerning the bolts on the SAS.**

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

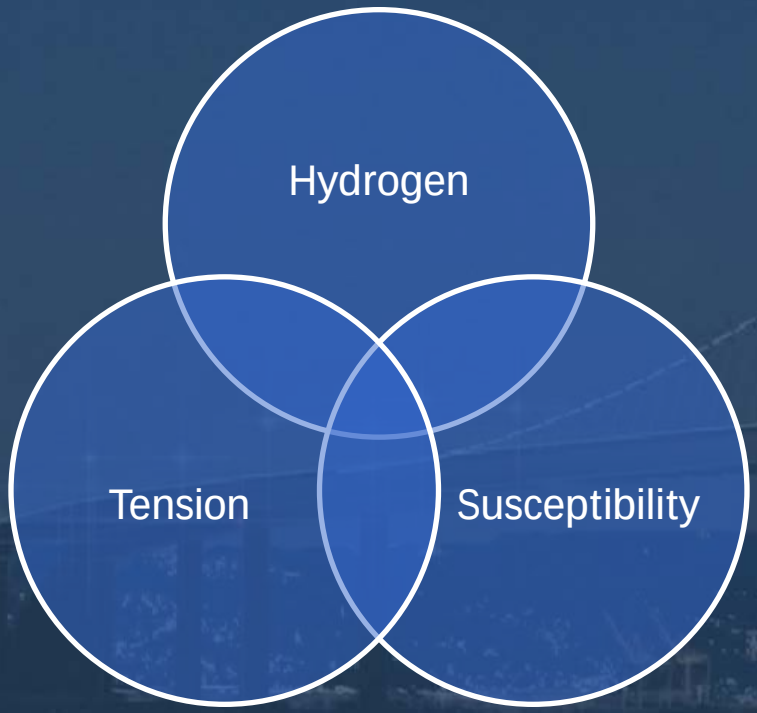


- **Bearings and shear keys are secured to E2 by 3 inch diameter bolts, ranging from 9 feet to 24 feet in length and to the OBG by 2 to 3 inch diameter bolts ranging 2 to 5 feet in length.**
- **96 bolts manufactured in 2008 shown in red are embedded in the pier.**

Failure of 2008 Bolts Due to Hydrogen Embrittlement

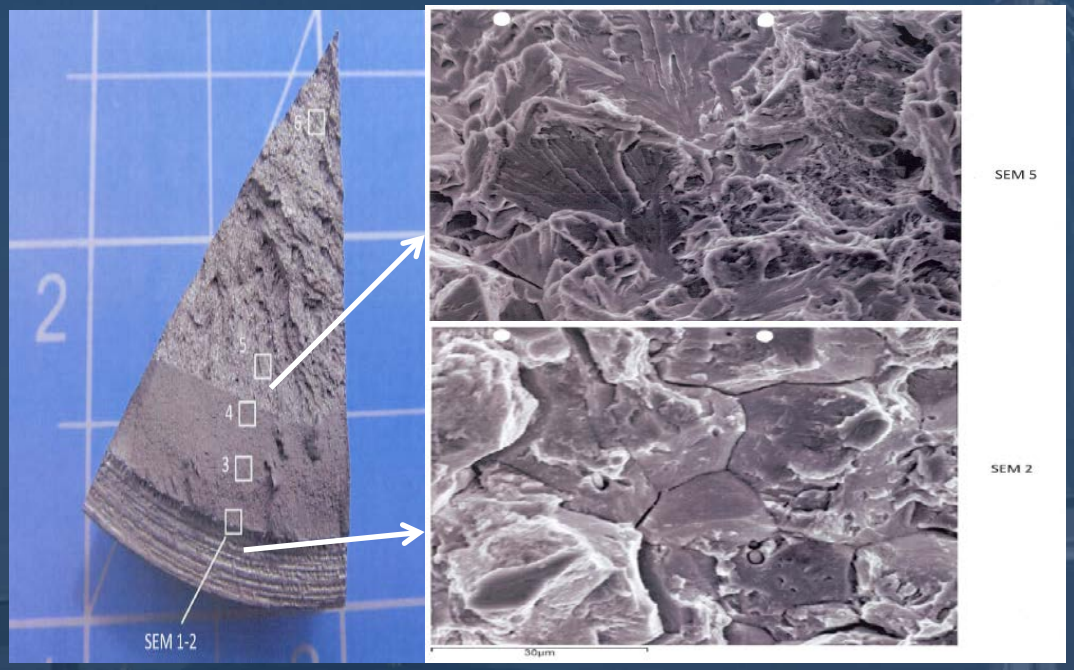
- As determined by Caltrans and the Contractor, the anchor bolts failed as a result of hydrogen embrittlement.

Hydrogen Embrittlement



- **Hydrogen embrittlement requires three elements**
  - **Susceptibility**
  - **Hydrogen**
  - **Tension**
- **Root cause of the failure is attributed to higher than normal susceptibility of the steel to hydrogen embrittlement.**

Hydrogen Embrittlement



1000X Magnification

- Metallurgical analysis shows a lack of uniformity in the microstructure of the steel, with large differences in hardness from center to edge and high local hardness near surface. Further, the material exhibited low toughness and marginal ductility.

Report Recommendation

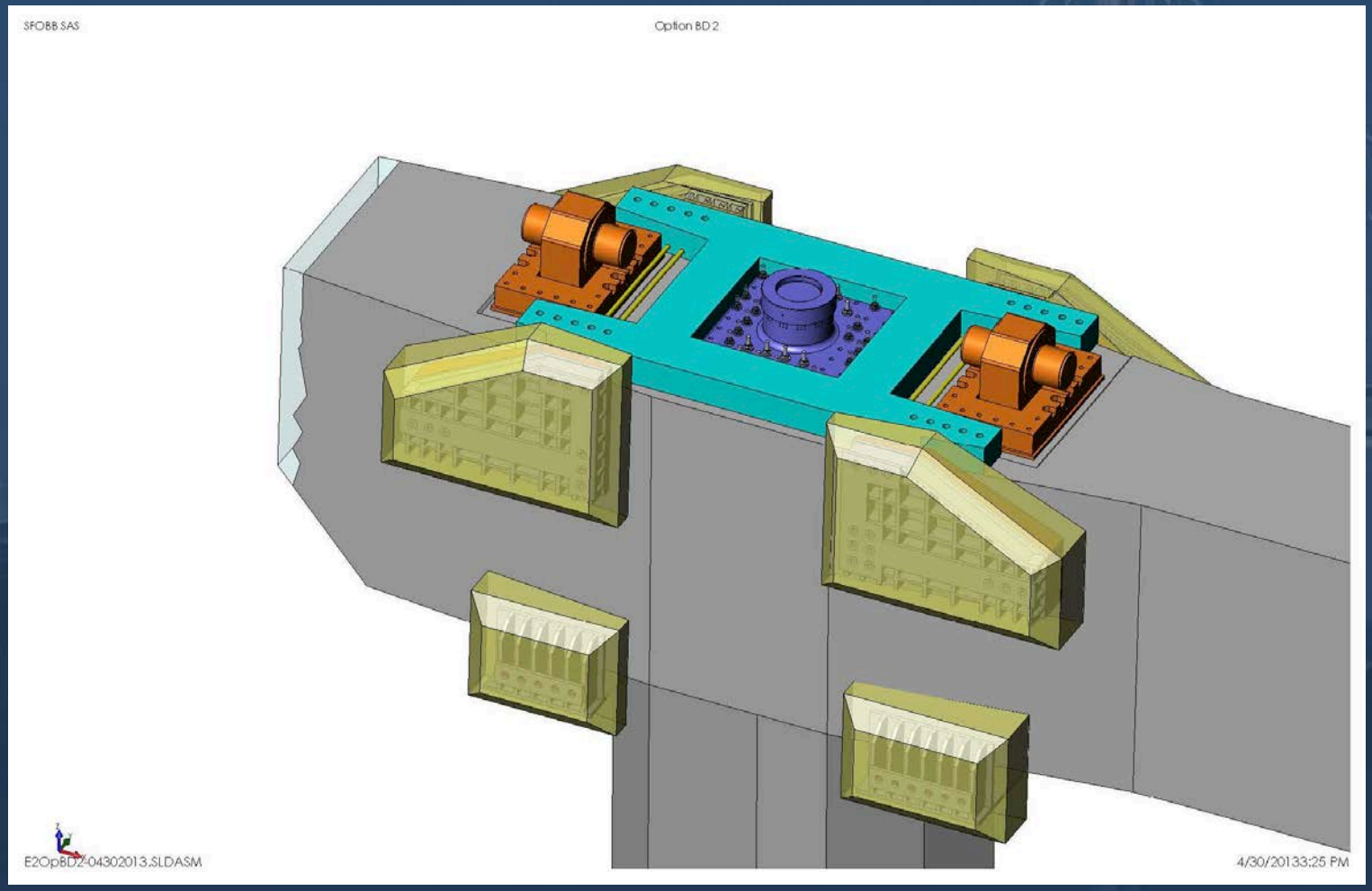
- **Procurement of future A354 grade BD anchor rods should include a number of supplemental requirements to assure against hydrogen embrittlement failure.**

Specifications for Galvanized A354 BD Bolts

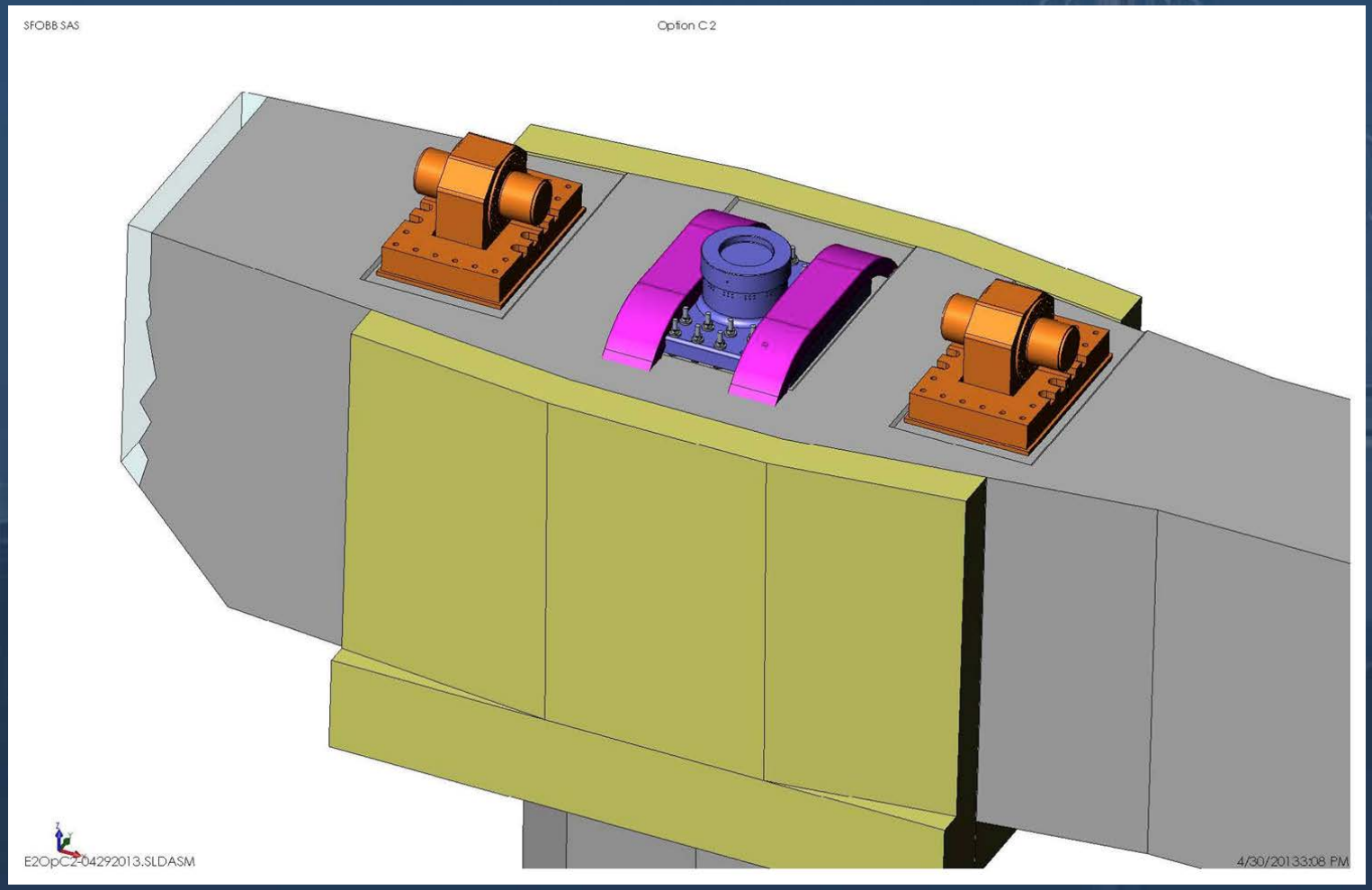
- A technical design specification team evaluated the bridge design and selected A354 BD bolts for this application.
- The design specification team subsequently added a supplemental requirement – blasting instead of pickling – to address the potential for hydrogen embrittlement.
- Current Caltrans Bridge specifications do not allow the use of galvanized A354 bolts for standard bridge applications, but non-standard applications may be considered. ASTM does allow galvanization, but cautions on the potential for hydrogen embrittlement.
- Caltrans has ordered a limited number of replacement bolts for the 2010 bolts subjected to destructive testing. The special provisions of the specifications for those replacements rods include, but is not limited to, tighter requirements for hardness and additional testing to address hydrogen embrittlement. In hindsight, these supplemental specifications should have been in place for the 2008 bolts.

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

Option 1 – Steel Collar



Option 2 – Steel Saddle



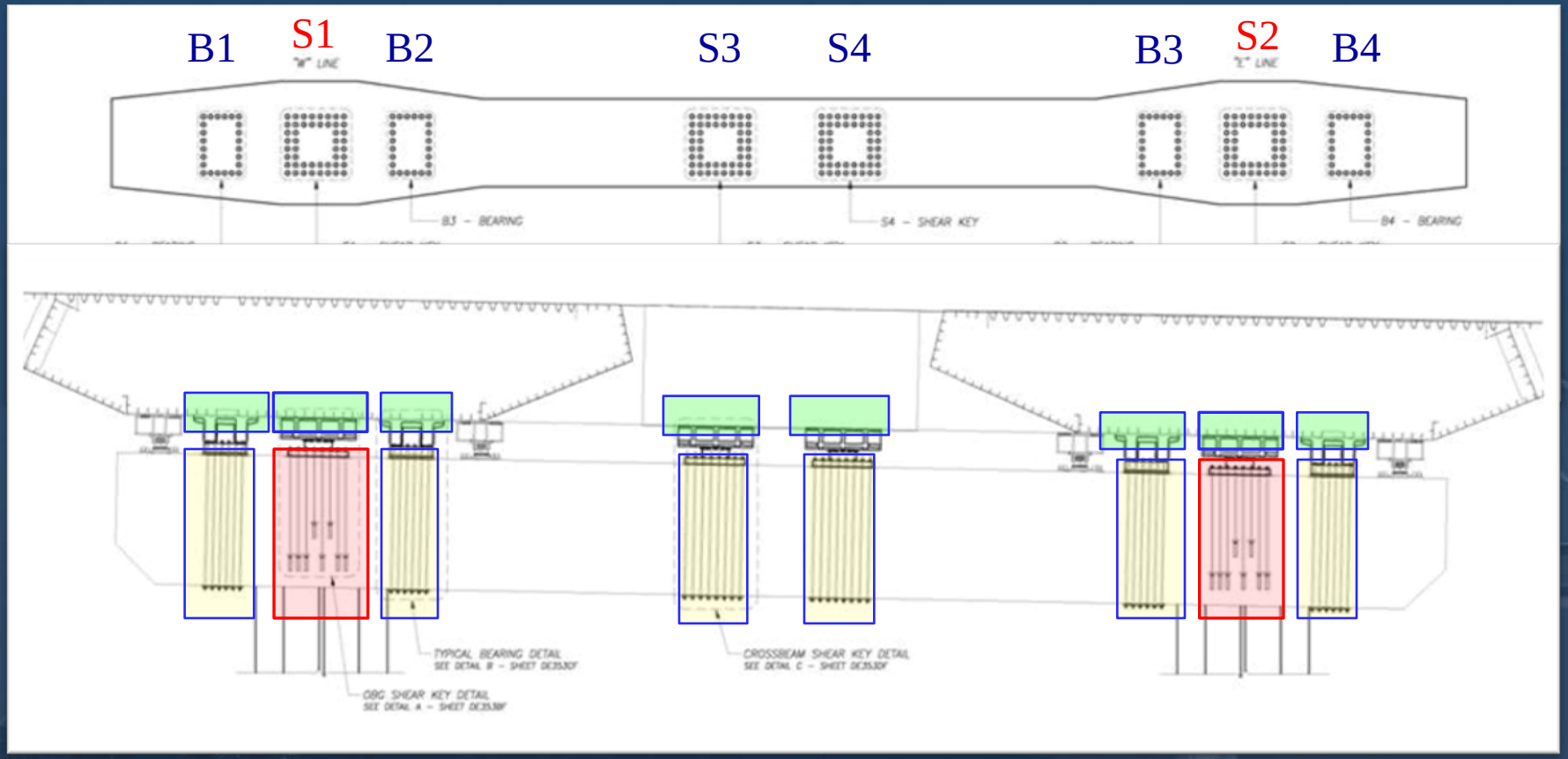
General Comparison of Options

Option 1 – Steel Collar	Option 2 – Steel Saddle
Pros • No need to remove S1 and S2 shear keys • Potentially simpler to fabricate	Pros • No need to remove S1 and S2 shear keys • Less coring of E2 required • Potentially less difficult to install. • Less costly: $5 to 10 m
Cons • Need to find sufficient materials and resources • More coring of E2 required • More costly: $15 to 20 m	Cons • Requires unique saddle system.

Selection of Option 2 - Saddle

- Both options would provide equivalent clamping force as the original bolt design to hold down the shear keys. The 2008 bolts will be completely abandoned in both options.
- Option 2 has been selected as the retrofit strategy for the 2008 bolts because while requiring more detailed fabrication, installation will be less difficult and require less coring of concrete on Pier E2.
- Estimated cost to construct Option 2 is $5 to 10 m.
- Given the complexities of the retrofit, Caltrans is still working with the Contractor to determine if the retrofit can be completed by Labor Day.

3. Should the remaining bolts on the E2 pier manufactured in 2010 be replaced?



- 96 bolts manufactured in 2008 shown in red are embedded in the pier.
- 192 bolts manufactured in 2010 shown in yellow are not embedded in pier.
- 544 bolts manufactured in 2010 shown in green are connected to the OBG.
- There are an additional 432 bolts of 1 inch diameter, varying from 2 inches to 2 feet in length, that are internal to the E2 bearing assembly.

Preliminary 2010 Bolt Results

- No bolts have broken after more than a month of tensioning.
- Preliminary test results for 2010 bolts, including full sized destructive testing, show more ductile material properties and no hydrogen embrittlement.
- Additional testing results are anticipated, including surface hardness, toughness, microscopic examination, and corrosion testing

	Tensile (KSI)	Yield (KSI)	Elongation (%)	Reduction of Area (ROA)	Hardness (HRC)	Charpy Toughness (ft-lb)
ASTM Requirements D>2 ½"	140 (min)	115 (min)	14 (min)	40 (min)	31-39	N/A
2008 E2 Bottom Average	164	142	14	48	37	@40° - 13.5 @70° - 16.2
2010 E2 Bottom Average	159	139	16	51	34	@40° - 37.2 @70° - 37.7
E2 Shear Key Top Average	159	141	16	46	35	N/A
ASTM Requirements D = ¼" to 2 ½"	150 (min)	130 (min)	14 (min)	40 (min)	33-39	N/A
E2 Bearing Top Average	161	135	16	54	35	N/A
E2 Bearing Assembly Average	166	154	18	56	36	N/A
E2 Retaining Ring Average	166	148	16	50	35	N/A

Wet Testing of 2010 Bolt Results

- A “wet” test is an accelerated test being prepared to determine the longer term susceptibility of the material to stress corrosion.
- Full sized bolts will be soaked in a controlled concentrated salt solution while tensioned progressively over a number of days until failure.
- Data from this test will be used to determine the susceptibility of the material to stress over time and under various loads.

Stress Corrosion

- **Long term stress corrosion susceptibility is a function of the size and hardness of material, and level of tensioning.**

- **With the "wet" testing data, staff will be able to evaluate all similar high-strength bolts used on the project and help determine if additional remedial action is needed.**

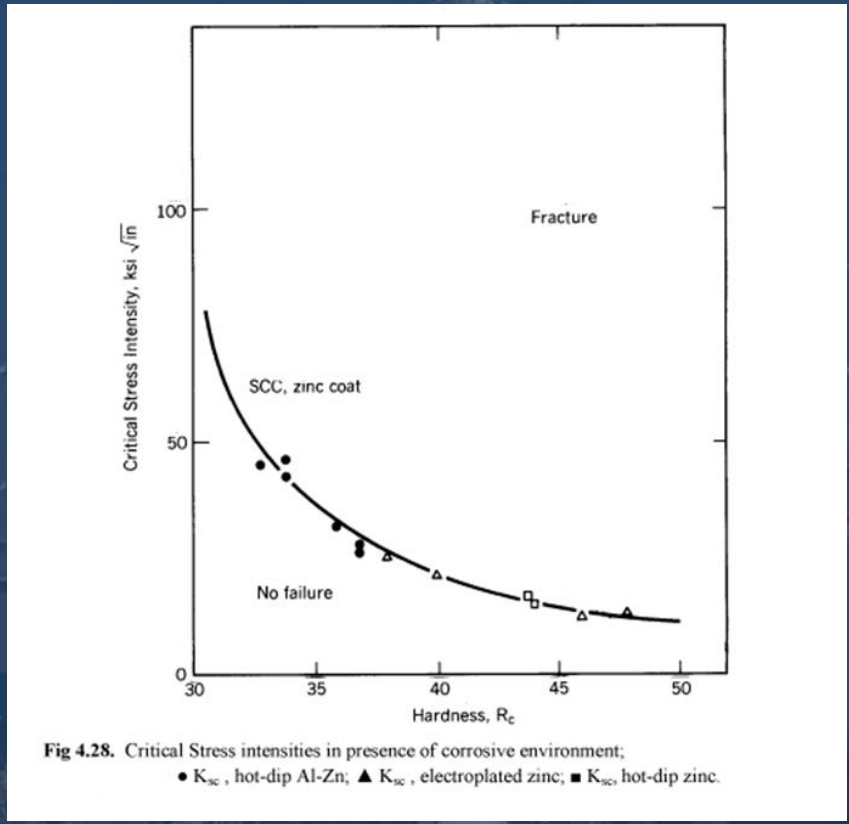
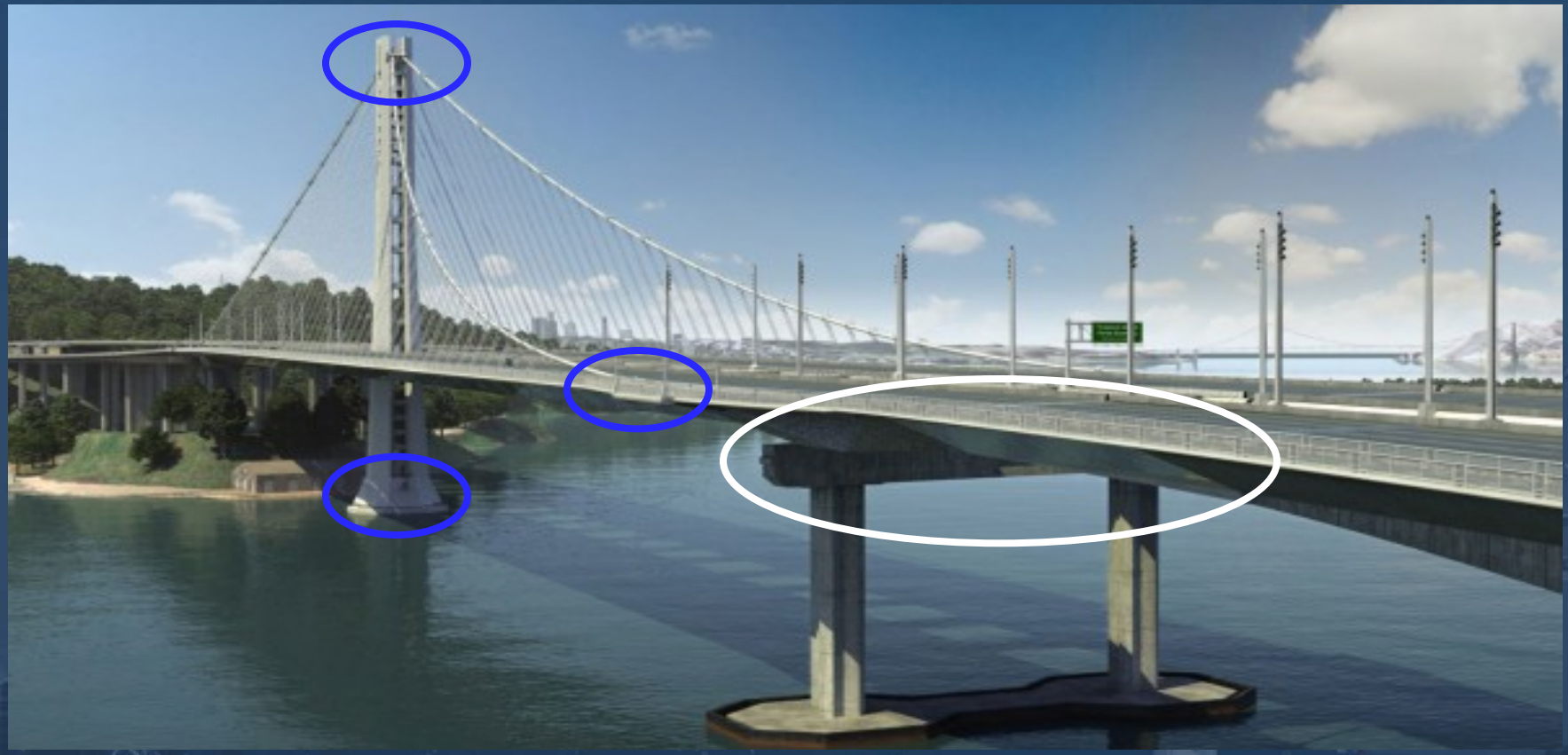


Fig 4.28. Critical Stress intensities in presence of corrosive environment; • K_{sc}, hot-dip Al-Zn; ▲ K_{sc}, electroplated zinc; ■ K_{sc}, hot-dip zinc.

Sample Critical Stress Curve from *Guide to Design Criteria for Bolted and Riveted Joints 2nd Edition* authored by Geoffrey Kulak, John Fisher, and John Struik and published by American Institute of Steel Construction

4. What should be done about other similar bolts on the SAS?



- Visual inspections of similar bolts revealed they are performing as required.
- Some E2 Bearing assembly bolts are not accessible to inspection.
- Most bolts at other locations are under lower tension levels.

Other Similar Bolts

Location	Item No.	Description	Diameter (in)	Length (ft)	Quantity Installed	Tension (fraction of Fu)
E2	1	2008 Shear Keys Bolts	3	10 – 17	96	0.7
	2	2010 Shear Keys and Bearing Bolts	3	22 - 23	192	0.7
	3	Upper Shear Key OBG Connections	3	2 - 4.5	320	0.7
	4	Upper Bearing OBG Connections	2	4	224	0.7
	5	Bearing Assembly Bolts for Bushings	1	2.5	96	0.6
	6	Bearing Assembly Bolts for Retaining Rings	1	0.2	336	0.4
Anchorage	7	PWS Anchor Rods	3.5	28 – 32	274	0.4
Top of Tower	8	Saddle Tie Rods	4	6.0 – 18	25	0.4
	9	Saddle Segment Splices	3	1.5 – 2	108	0.1 - 0.5
	10	Saddle to Grillage Anchor Bolts	3	1	90	0.1
	11	Outrigger Boom	3	2	4	0.1
Bottom of Tower	12	Anchor Rods 3"	3	26	388	0.5
	13	Anchor Rods 4"	4	26	36	0.4
East Saddles	14	East Saddle Anchor Rods	2	3	32	0.1
	15	East Saddle Tie Rods	3	5	18	0.1
East Cable	16	Cable Bands	3	10 - 11	24	0.2
W2	17	Bikepath Anchor Rods	1 3/16	1.5	43	tbd
				TOTAL	2306	

Other Toll Bridges

- As part of this investigation, the TBPOC has asked Caltrans to review other toll bridges which may have used similar bolts.

- Caltrans has already identified locations of similar A354 BD galvanized bolts on the Richmond-San Rafael Bridge and completed initial inspections.

- No issues have been found and bolts are performing as required.

Items Expected From Briefing at Special May 29th BATA Meeting

- Pending results from testing of 2010 bolts, decision on whether to replace other Pier E2 bolts and, if so, when.

- Completion of desk review of additional QA/QC results for other high tension anchor bolt locations.