

INFORMATIONAL HEARING

**CALTRANS:
THE STATE AUDITOR'S RECENT INVESTIGATION
AND A BAY BRIDGE UPDATE**

Tuesday, May 14, 2013
1:30 p.m. – John L. Burton Hearing Room (4203)

AGENDA

I. Opening Remarks

II. State Auditor's Recent Investigation

Elaine Howle – California State Auditor

Malcolm Dougherty, Director – California Department of Transportation

Cris Rojas, Deputy Director, Administration – California Department of Transportation

III. Bay Bridge Update

Malcolm Dougherty, Director – California Department of Transportation

Andre Boutros, Executive Director – California Transportation Commission

Steve Heminger, Executive Director – Metropolitan Transportation Commission

Tony Anziano, Toll Bridge Program Manager – California Department of Transportation

Brian Maroney, Bay Bridge Principal Engineer – California Department of Transportation

Dr. John Fisher, Professor Emeritus of Civil Engineering – Lehigh University

IV. Public Comment

Senate Transportation and Housing Committee

Informational Hearing

Caltrans: The State Auditor's Recent Investigation And a Bay Bridge Update

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BACKGROUND PAPER

The California Department of Transportation (Caltrans), with roughly 20,000 employees and an annual budget of nearly \$13 billion, is responsible for planning, coordinating, and implementing the development and operation of the state's transportation system. Within this responsibility falls the development and construction of the new eastern span of the San Francisco-Oakland Bay Bridge (Bay Bridge). The Bay Area expected the new "signature span" to be designed with distinction and dramatic appearance, unique and worthy of the world-class region. Under construction since 2002 and originally scheduled to open in 2007, Caltrans now plans to open the new span to traffic Labor Day weekend of 2013. The most recent cost estimate for the project is \$6.3 billion.

The Bay Bridge is the largest single public works project in state history, and the culmination of years of design and construction effort. The new span is a "self-anchored suspension" bridge, which means the main cables attach to the ends of the bridge deck rather than to the ground via large anchorages. This type of design, while often beautiful to view, is also well-suited in areas of unstable soils where anchorages would be difficult to construct. Caltrans engineered the new span to withstand the largest earthquake expected over a 1500-year period, and expects the bridge to last at least 150 years with proper maintenance.

The May 14th hearing is the latest in a line of informational hearings about Caltrans by this committee to maintain the Legislature's oversight role of the administration.

This hearing is composed of two panels. First, the California State Auditor will present the results of a recent investigation involving the falsification of testing data and misappropriation

of state property by Caltrans employees. Then, Caltrans and other experts will discuss the recent problems experienced with the Bay Bridge, specifically the failure of high-strength steel rods holding the bridge in place. This background report first presents a summary of the State Auditor's investigation and findings. Then it reviews what Caltrans and experts have determined about the anchor bolt issues. Finally, this report considers what the concerns raised in recent years as well as those discussed in this hearing might suggest about Caltrans itself.

PART I – The State Auditor's Investigation

The California Whistleblower Protection Act (Government Code section 8547, et seq) authorizes the California State Auditor (Auditor's office) to investigate and report on improper governmental activities by state agencies and employees. After receiving information in early 2009 that certain Caltrans technicians might be receiving overtime and differential payments for work not performed, the Auditor's office asked Caltrans to assist with an investigation by reviewing all 2008 timesheets for these technicians. After this request, and in response to a complaint that Caltrans received in 2009, Caltrans and two federal agencies—the Office of the Inspector General for the United States Department of Transportation and the Federal Highway Administration (FHWA)—initiated related investigations into the falsification of testing data and misappropriation of state property by Caltrans employees in its Foundation Testing Branch.

Caltrans did not provide the Auditor's office with the results of its review of the technicians' timesheets until September 2009, despite repeated requests for a quicker response. When the Auditor's office finally received the results of the review and examined Caltrans' methodology, it found the review to be inadequate, as Caltrans did not explain how the technicians could have worked so much overtime on days when they were not assigned to perform testing in the field. In January 2010, the Auditor's office asked Caltrans to explain why the technicians' overtime hours were not associated with field testing and to review supporting documents to ensure the technicians worked all of the hours they claimed.

Caltrans responded that the overtime hours claimed by the technicians were incurred while performing tasks associated with conducting tests in the field. When comparing the technicians' travel claims to their overtime and testing hours, however, the Auditor's office found that most of the overtime and testing hours claimed were not associated with field testing. Instead, the technicians claimed overtime and pile load testing hours regularly, without regard to their assignments. From March 2010 through October 2011, the Auditor's office repeatedly asked Caltrans to provide it with updates on the status of its work. Caltrans

submitted its final report to the Auditor in October 2011. After reviewing Caltrans' report, however, the Auditor's office found that it needed to conduct additional interviews and perform additional analyses to validate Caltrans' findings, which led to further delay of the Auditor's final report.

In conclusion, the Auditor's investigation revealed that a Caltrans supervisor neglected his duty to supervise two technicians, which facilitated their being able to get paid for work they did not perform. In 2008, these technicians improperly claimed overtime and differential pay for work not performed, costing the state an estimated \$13,788 in overpayments to the technicians. In addition, Caltrans employees engaged in 11 incidents of data falsification. The supervisor of these technicians also made improper use of Caltrans property by taking it to land that he owned near Susanville, California, with help from the two technicians and other subordinate employees. The Auditor's office began its investigation into Caltrans in early 2009, but did not release its final report until four years later, primarily due to Caltrans' slow response and inadequate internal investigation.

According to the Business, Transportation, and Housing Agency's response to the Auditor contained in the final report, Caltrans took disciplinary action against the technicians and the supervisor for their identified improprieties. One technician retired from state service with the commitment that he never work for the state again, while Caltrans suspended the other technician for a period of time and is now back at Caltrans. Caltrans terminated the supervisor, and the State Personnel Board upheld the termination in March of 2013. Caltrans has suggested that, despite clear evidence of improper or illegal activities, these disciplinary actions were hard-fought and expensive endeavors.

To remedy the effects of the improper governmental activities described in its report and to prevent them from recurring, the Auditor's office made a number of recommendations.

First, to address the false claims for overtime and differential work hours submitted by the technicians, the Auditor's office recommended that Caltrans:

- Seek roughly \$14,000 in reimbursement from the two technicians for the overtime and pay differential payments that they received improperly.
- Establish a system to enforce the requirement that specific overtime hours be preapproved for an employee to be compensated for the hours.

- Reinforce with Caltrans supervisors that they have a duty to verify that overtime and specially compensated work actually has been performed prior to authorizing payment for the work.
- Require the hours of overtime and differential work claimed by an employee to be matched with specific projects before they are approved for payment to help ensure that the hours claimed are legitimate.

Second, to address the lack of controls that allowed testing data falsification, the Auditor's office recommended that Caltrans:

- Require that Foundation Testing Branch technicians submit to an engineer the raw data files for every test performed on a project to help ensure that a technician has not falsified the testing data.
- Implement the recommendations of the peer reviewers intended to improve the testing procedures of the Foundation Testing Branch.
- Implement a policy to ensure that engineers perform analyses on properly collected data and do not misrepresent test results.

Third, to address the misappropriation of state property by the supervisor or other Caltrans employees, the Auditor's office recommended that Caltrans:

- Seek reimbursement from the supervisor for the cost of the Caltrans materials that he transported to his land and the cost of the state employee time spent transporting and refashioning those materials.
- Seek reimbursement from the supervisor for the \$2,000 cost of transporting the steel beams that he placed on his land back to a Caltrans facility.
- Establish controls to ensure that materials intended for a construction project are tracked properly, and that when materials intended for a federal highway project are not used for the project, the materials are reused for other federal projects or returned to FHWA.
- Establish controls to ensure that Caltrans employees recycle scrap materials and do not take them for personal use.

Caltrans' Response to the Auditor's Investigation

According to the Auditor's Report, Caltrans has taken a number of steps to address issues raised during the investigation. First, Caltrans stated that it could not seek reimbursement for false overtime claims from the technicians because it had already reached settlement agreements with them. Caltrans reported, however, that it made revisions to its overtime policy and has communicated to supervisors what expectations it has going forward in administering the policy. Second, Caltrans reported that it has made adjustments to its testing procedures to try and address the potential for falsification of testing data in the future. Third, Caltrans reported that it filed a civil action against the supervisor seeking the return of stolen materials or compensation for them. Finally, Caltrans plans to implement a new management system in July of 2013, that will allow it to track the purchase and subsequent use of all materials used on federal projects.

PART II – The Bolts on the Bay Bridge

A self-anchored suspension bridge essentially holds the weight of the road bed up with its main cables balanced over the center tower. It is important, however, that both ends of the bridge maintain precise contact with the approaches on either side. In order to maintain this contact, the road beds are secured to concrete piers jutting from the bay by mechanical fixtures called shear keys and bearings. These fixtures maintain the bridge's connection to the piers in the event of a major seismic event, allowing the bridge to move, but not move too far. Anchor bolts 3 inches in diameter and ranging from 9 feet to 24 feet in length hold these fixtures in place. Because these fasteners are unique, a specialized subcontractor in Illinois manufactured the anchor bolts to meet specifications determined by Caltrans to be necessary for this bridge. The subcontractor manufactured 96 of these anchor bolts in 2008 (2008 bolts) and 192 additional bolts in 2010 (2010 bolts).

There are many different parameters to consider during the manufacture of bolts or other fasteners. The American Society for Testing and Materials

Hydrogen Embrittlement

There are many theories on the exact cause of hydrogen embrittlement, but essentially any chemical process that introduces hydrogen into the steel can lead to embrittlement. This can occur during the manufacturing process, while galvanizing the fastener, or even if the fastener is exposed to caustic or sour environments. What is known is that the harder the steel, and when galvanized a particular way, the more likely the fastener is to suffer from hydrogen embrittlement and fail once tensioned.

International (ASTM) is an organization that develops and publishes voluntary technical standards for a wide range of materials and products, such as for bolts and fasteners. ASTM fastener standards include measures of tensile strength (the maximum tension a bolt can support prior to or coinciding with its fracture), ductility (the ability of a material to deform before it fractures), and hardness (a measure of a material's ability to resist abrasion and indentation). Generally speaking, the higher the level of tensile strength and hardness, the lower the level of ductility of a given bolt or fastener. In addition, the harder and stronger the bolt, the more susceptible it becomes to hydrogen embrittlement, an affliction where hydrogen atoms invade the spaces between a steel rod's crystalline structure and causes a tensioned bolt to fail suddenly without warning. Galvanization, or the process of applying a protective zinc coating to steel or iron in order to prevent rusting, also increases the potential for hydrogen embrittlement.

Caltrans specifications given to the specialized subcontractor required the anchor bolts to be manufactured to standards akin to A354 BD bolts. According to ASTM, A354 BD bolts tend to be on the stronger, harder end of the steel fastener spectrum. In fact, when Caltrans tested the specially manufactured bolts upon delivery, they tended to be even harder and stronger than A354 BD specifications. For example, while the minimum tensile strength of A354 BD bolts is 140,000 pounds per square inch (psi), the delivered anchor bolts ranged from 152,000 to 173,000 psi. In addition, because the manufacturer was making these particular fasteners for an overwater bridge, Caltrans specifications called for the anchor rods to be galvanized.

Experts suggest that the experience with very high-strength steels in marine environments has been very poor. The benefit of high-strength steel is that less of it is required to meet expected stress demands. But too much strength leads to lower ductility, and galvanization can exacerbate this weakness due to the higher potential for hydrogen embrittlement. FHWA recognized this threat and recommended against using galvanized high-strength steel fasteners on bridges at least as early as 1991. In fact, the February 2004 version of Caltrans' own bridge design specifications forbids the use of galvanized A354 BD high-strength bolts due to hydrogen embrittlement problems. In designing the Bay Bridge, Caltrans exempted the bridge from the state's own bridge design specifications – a practice that is not uncommon for unique structures.

On March 1st of 2013, workers tightened the 2008 bolts installed on the bridge. Within 14 days, one-third or 32 of the 96 anchor rods had fractured, and Caltrans decided to de-tension the rest of the bolts. Because of the way the bridge was constructed, Caltrans cannot remove and

replace these 96 bolts. They are embedded in the bridge. Caltrans and its contractors are currently designing a retrofit strategy to replace the functionality of the 2008 bolts.

Recognizing the failure of the 2008 bolts, Caltrans has also begun assessing the use of galvanized A354 BD bolts elsewhere on the Bay Bridge. In April, Caltrans tightened the 2010 bolts to determine whether they, too, will fail due to hydrogen embrittlement. After 15 to 25 days under tension, none of the 2010 bolts have failed. The bridge design allows for the replacement of the 2010 bolts, however, and Caltrans is studying whether or not it should replace the 2010 bolts. In addition, there appear to be more than 2,000 other high-strength, galvanized bolts installed on the bridge, and Caltrans is inspecting them all to determine whether or not they need to be replaced. Caltrans has requested from FHWA an independent review of its findings and recommendations concerning the anchor bolts.

As experts explain, the anchor rod failures are a classic case of bad materials engineering. Some suggest that the confusion surrounding the anchor rod failures reflects the lack of expertise by Caltrans and its contractors in materials engineering and, specifically, in the nature of hydrogen embrittlement. Caltrans' specifications only contained a minimum hardness requirement, not a maximum surface hardness. In addition, Caltrans apparently addressed the hydrogen embrittlement threat only from the possibility of hydrogen entry into the steel rods during the manufacturing process. Experts claim, however, that the most important factor in high-strength steel rod failures due to hydrogen embrittlement is the steel's hardness. Caltrans did not address this threat when specially ordering the high-strength bolts.

The bottom line is that the use of steel fasteners on projects of this magnitude is very complicated and not at all black and white. Experts do not agree on what should or should not be used. Though most experts recommend not using steel as hard as the anchor rods in the Bay Bridge, varying factors including where the steel is produced, how it is heated, how it is galvanized, and the level of tensioning bear great significance on the performance of the fastener. Standards such as those recommended by ASTM are for typical-sized bolts, and the Bay Bridge is very unique because of its size, location, and the ever-present seismic threat.

PART III – Caltrans Issues

While this hearing focuses on the recent State Auditor investigation of Caltrans as well as the anchor bolt failures on the Bay Bridge, problems with the Bay Bridge project in the last few years have raised concerns about Caltrans' ability to oversee such large, complicated projects. The timeline below describes two things. First, it covers the general timeline of the anchor

bolts issue. Second, it includes recent concerns the media has raised about the design and performance of the Bay Bridge.

Figure 1: A Bay Bridge Timeline

1989	Loma Prieta Earthquake strikes Bay Area
2002	Final Design approved with galvanized steel bolts
2004	Caltrans updates Bridge Design Specifications First set of bolts ordered
2008	First set of bolts received, tested, installed
2009	Inspection issues uncovered
2011	Foundation issues uncovered Foundation review determines it is safe
2012	Seismic Peer Review Panel conflicts uncovered
2013	February LAO Panel begins work
	March 1 First set of 96 bolts tightened
	March 15 32 fractured bolts discovered
	April 1 Fractured bolts reported by the media
	May 1 Welds issue uncovered
	September New span currently scheduled to open

When the media discovered testing anomalies with the foundation of the self-anchored suspension tower, Caltrans' response was to review its own testing data and reassure the public that the bridge was safe. Caltrans also enlisted FHWA and its own Seismic Peer Review Panel to review the data. All reviews concluded that there was no cause for concern with the foundation.

The media then raised concerns about the independence of Caltrans' review panel, which prompted this committee to enlist the Legislative Analyst's Office (LAO) to review the reviews and provide some closure on the foundation safety concerns. The LAO put together an

independent panel of experts to review the documents and report to the committee. That report is due June 30, 2013.

This spring, the media reported the anchor bolt failures as described earlier, raising a new set of concerns about the bridge's safety. Caltrans is actively working on a solution to this new problem. Again, Caltrans reassures the public that, despite this bolt issue, the bridge is safe.

A few weeks ago, the media raised new questions about welds on the main tower foundation. Again, Caltrans' response is that the bridge is safe and the public need not worry.

As the media and experts force Caltrans to be accountable on these issues, and concerns about the bridge keep coming up, some wonder whether there are many more issues with the bridge that Caltrans hasn't yet shared. At some point, the question becomes whether there is an underlying reason for these issues that is made clear through a high-profile project like the Bay Bridge?

The Rogers Commission

One useful approach to examining Caltrans and the problems associated with the Bay Bridge may be to compare the current situation to historical experience. President Ronald Reagan created the Rogers Commission in 1986 to investigate the Space Shuttle Challenger disaster. The Rogers Commission concluded that a faulty design led to the failure of an o-ring on the solid rocket booster, which shot pressurized gases and eventually flame into the adjacent external tank, causing structural failure of the shuttle 73 seconds into its launch on January 28, 1986. While not at the same dramatic level of an exploding shuttle, the Bay Bridge is a similarly complex project suffering similar seemingly simple engineering problems. Therefore, it could be instructive to study the conclusions the commission drew in process of its investigation.

Despite being originally tasked to answer the question of why the Challenger exploded, the commission probed further to determine the contributing causes of the accident. The commission concluded that the space shuttle's solid rocket booster problem began with the faulty design and increased as both NASA and contractor management first failed to recognize it as a problem, then failed to fix it, and finally treated it as an acceptable flight risk. The genesis of the Challenger accident began with decisions made in the design of the solid rocket booster, and neither the contractor nor NASA responded adequately to internal warnings about the faulty seal design. Essentially, past shuttle launches experienced o-ring erosion and nothing untoward happened. Therefore, the risk was no longer so high for following flights. NASA

believed that because they got away with it the last time, they could lower their safety standards a little more for future flights.

In addition to analyzing the material causes of the Challenger accident, the commission examined the chain of decisions that culminated in approval of the fateful launch. Testimony before the commission revealed failures in communications that resulted in a decision to launch based on incomplete and sometimes misleading information, a conflict between engineering data and management judgments, and a NASA management structure that permitted internal flight safety problems to bypass key managers. While admittedly significant, the commission concluded that the problems that led to the Challenger disaster should be addressed by NASA internally, and that there was no need for NASA to suspend its operations or receive less funding.

Dr. Feynman's Findings

One of the Rogers Commission's best-known members was theoretical physicist Richard Feynman, Nobel-prize winner and active contributor to the Manhattan Project work. Dr. Feynman revealed a disconnect between NASA's engineers and executives that was far more striking than he expected. Specifically, Dr. Feynman concluded that NASA needed to take a hiatus from shuttle launches until it could resolve its internal inconsistencies and present an honest picture of the shuttle's reliability. While his fellow commission members were against a major overhaul, Dr. Feynman published a minority report as an appendix to the final report outlining his arguments for the rethinking of the organization.

In his appendix, Dr. Feynman, in part, used an analysis of the design of the space shuttle main engines to determine whether the organization weaknesses that contributed to the accident were confined to the solid rocket booster sector or if they were a more general characteristic of NASA.

Dr. Feynman suggests that the usual way major engineering projects such as the engines are designed is called the component system, or bottom-up design. First, it is necessary to thoroughly understand the properties and limitations of the materials to be used. Then larger component parts are designed and tested individually. As deficiencies and design errors are noted, they are corrected and verified with further testing. Since one tests only parts at a time, these tests and modifications are not overly expensive. Finally, one works up to the final design of the entire engine, to the necessary specifications. There is a good chance by this time that

the engine will generally succeed, or that any failures are easily isolated and analyzed because the failure modes, limitations of materials, etc., are so well understood.

Dr. Feynman discovered that the design of the space shuttle main engine was handled in a different manner. The engine was designed and put together all at once with relatively little detailed preliminary study of the materials and components. Then, when troubles were found in the engine's different components, it was more expensive and difficult to discover the causes and make changes. Further, using the completed engine as a test bed to resolve such questions was extremely expensive and inefficient. Dr. Feynman surmised that this top-down design method led to overly complicated engineering solutions that were hard to communicate to anyone outside the core design team. Without detailed understanding, confidence in the design could not be attained.

Finally, Dr. Feynman described the space shuttle main engine as a very remarkable machine built at the edge of, or outside, previous engineering experience. Therefore, as expected, many different kinds of flaws and difficulties turned up. Because, unfortunately, it was built in the top-down manner, however, the project's flaws became difficult to find and fix.

As for NASA, Dr. Feynman concluded that it must live in reality when comparing the costs and utility of the shuttle to other methods of entering space. NASA must be realistic in making contracts, in estimating costs, and determining the difficulty of its projects. If, given a realistic picture, the government would not support them, then so be it. Dr. Feynman wrote that NASA owes it to the citizens from whom it asks support to be frank, honest, and informative, so that these citizens can make the wisest decisions for the use of their limited resources.

Parallels to Bay Bridge Project

Caltrans and other experts describe the Bay Bridge as one of the most complicated bridge projects in the world. It is the largest self-anchored suspension bridge ever built further complicated by the seismic challenges of the Bay Area. The designers admit that throughout the process the bridge was designed on the edge of common engineering experience and knowledge and therefore susceptible to unknowns such as the breaking anchor rods. Notwithstanding all the issues that have been raised, Caltrans and other experts claim the bridge is still significantly safer than the existing Bay Bridge.

Some have suggested that many of the failures of the bridge today stem from the fact that the bridge was designed in a top-down manner, not the component system or bottom-up design

method described by Dr. Feynman. For example, the anchor bolts may have been designed to be as hard as they were because, in the design, there was not the room to use more but less-hard steel fasteners. The design would not allow the less-susceptible material to hold the seismic fixtures to the pier because there wasn't enough space to employ the amount of metal necessary to hold the bridge together. In this way, form dictated function, resulting in bolts that were too hard and susceptible to hydrogen embrittlement and ultimately to failure.

A number of newspaper editorial boards in the Bay Area have called for independent review of the current bolt problem and of Caltrans' handling of the project as a whole. Unfortunately for Caltrans, it appears the department has lost some credibility. Some have suggested that because the public may not have faith in Caltrans, it is becoming more difficult to reassure the public about the safety of the bridge.

PART IV – Conclusion

The subject of the May 14th hearing raises many questions that need answers. The first level of answers sought includes what Caltrans and its contractors will do to resolve the immediate problem of bolt failures. This engineering solution, with the expertise available, should be readily provided in a short time. Second, Caltrans needs to address the testing process that did not recognize or identify the clear opportunity for failure of the 2008 anchor rods before they were installed. Caltrans has suggested that, in retrospect, had they completed another type of test on the rods upon delivery they might have been able to avoid the need for the retrofit today.

On an even deeper level, Caltrans needs to answer the questions of how and why it chose these high-strength, galvanized steel bolts in the bridge design to begin with. This question leads to examining Caltrans as an organization and its ability to handle the development of these large, complex infrastructure projects.

- Is this a case of top engineers and designers, given an outsized goal, reaching too far beyond our own understanding? Or were the bridge developers, so driven by design, forced to adopt unreliable methods in order to fit a mold only tangible in dreams?
- Given that all major projects experience some form of setbacks and unforeseen events, are the problems with the Bay Bridge minor and resolvable, or are they symptoms of larger challenges within Caltrans?

Ultimately, Californians need to know whether the new span of the Bay Bridge is safe. It is becoming increasingly difficult for the Legislature and the public to simply believe in Caltrans' reassurances when problems continue to arise and the experts who designed and constructed the bridge give the "all clear." While it is unarguable that the current bridge is unsafe and therefore critical to retire, it seems a truly independent third-party validation of the new span's design and construction may be necessary to determine its level of safety. There are a number of ways that can be done, such as enlisting a cadre of University of California professors, or hiring a federally-funded non-profit think tank to complete the validation. But the Californians who ultimately paid for the bridge deserve a frank, honest, and informative discussion of the new span to determine what they purchased.

Briefing on E2 Anchor Bolts – May 14, 2013



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY CALIFORNIA TRANSPORTATION COMMISSION

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?





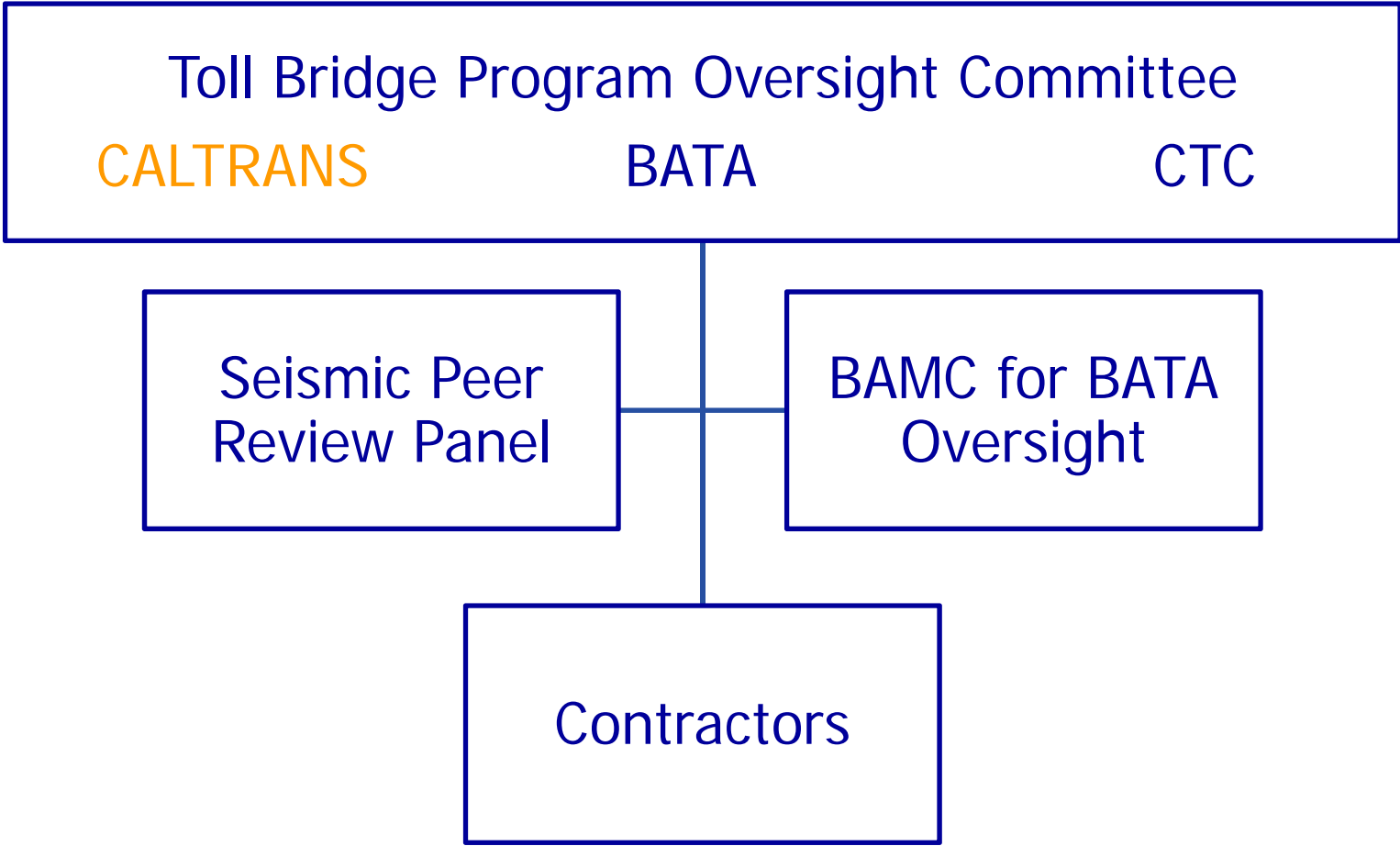
Pier E2



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY CALIFORNIA TRANSPORTATION COMMISSION

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



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY 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.



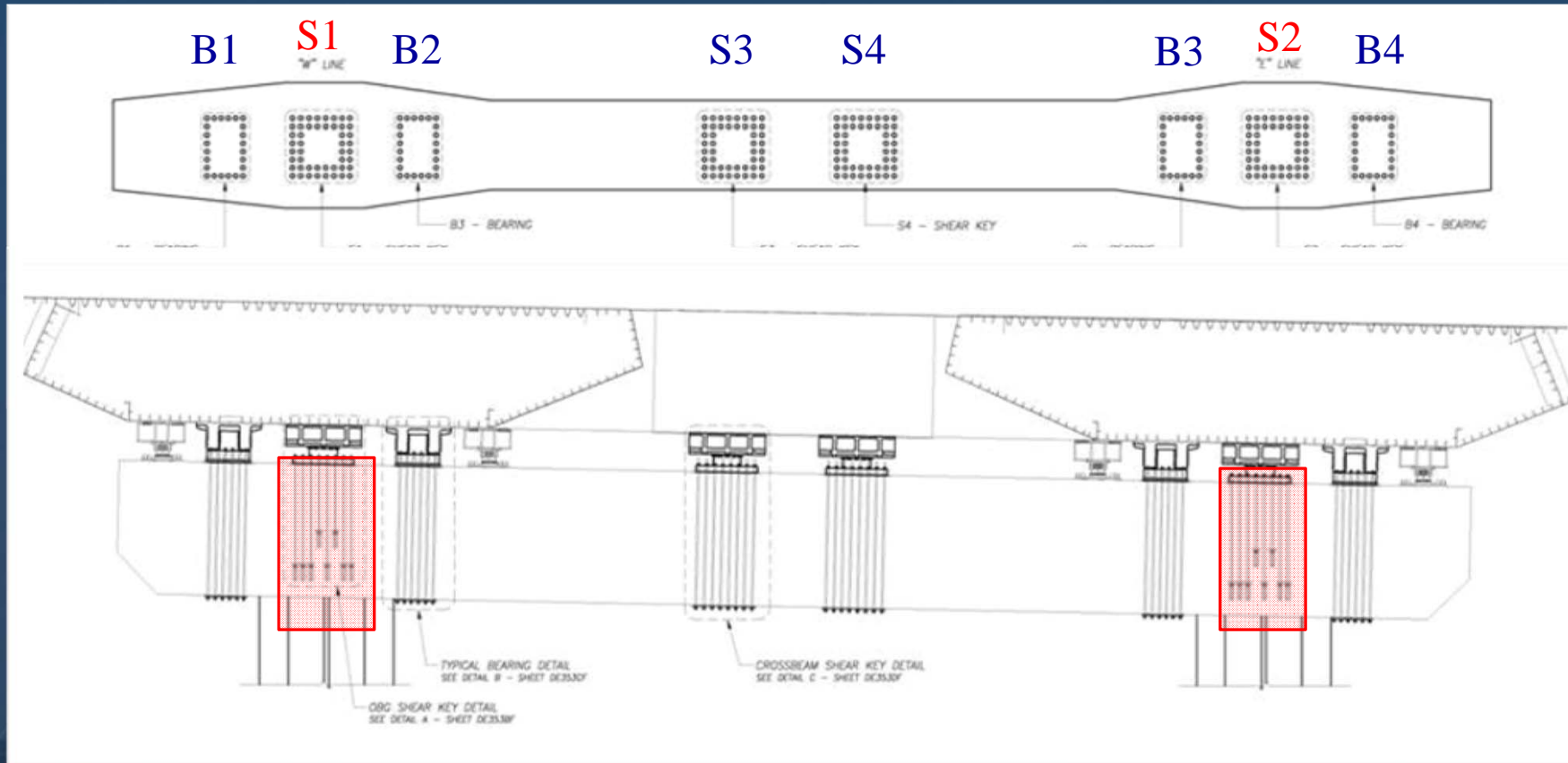


1. What caused the E2 anchor bolts manufactured in 2008 to fail?



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY CALIFORNIA TRANSPORTATION COMMISSION



- 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.



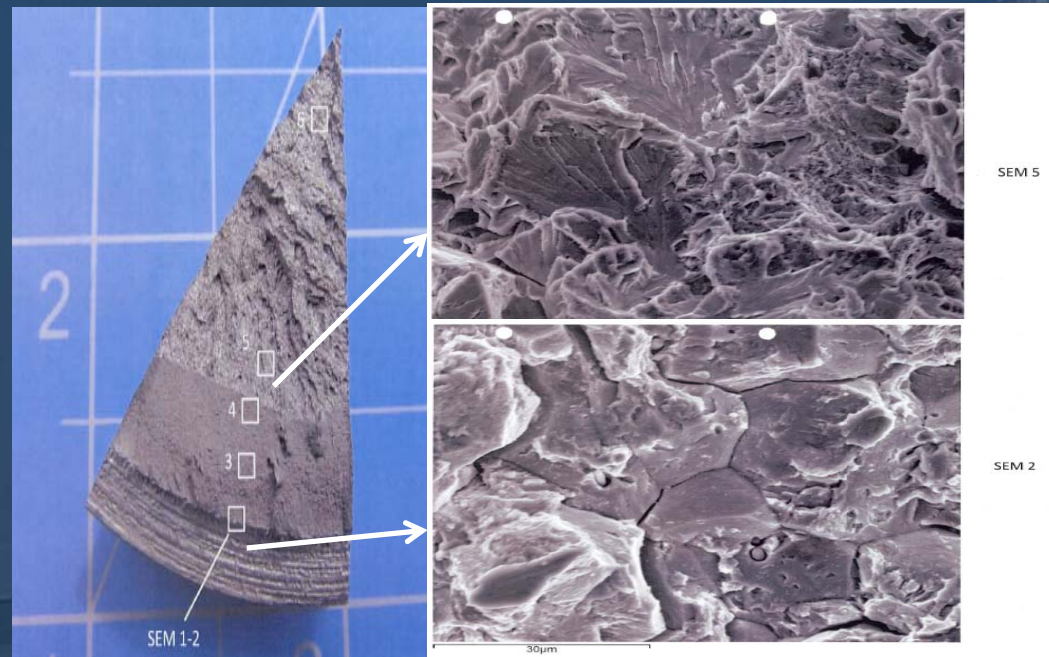
Hydrogen Embrittlement



- **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.



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

CALTRANS BAY AREA TOLL AUTHORITY CALIFORNIA TRANSPORTATION COMMISSION

Report Recommendation

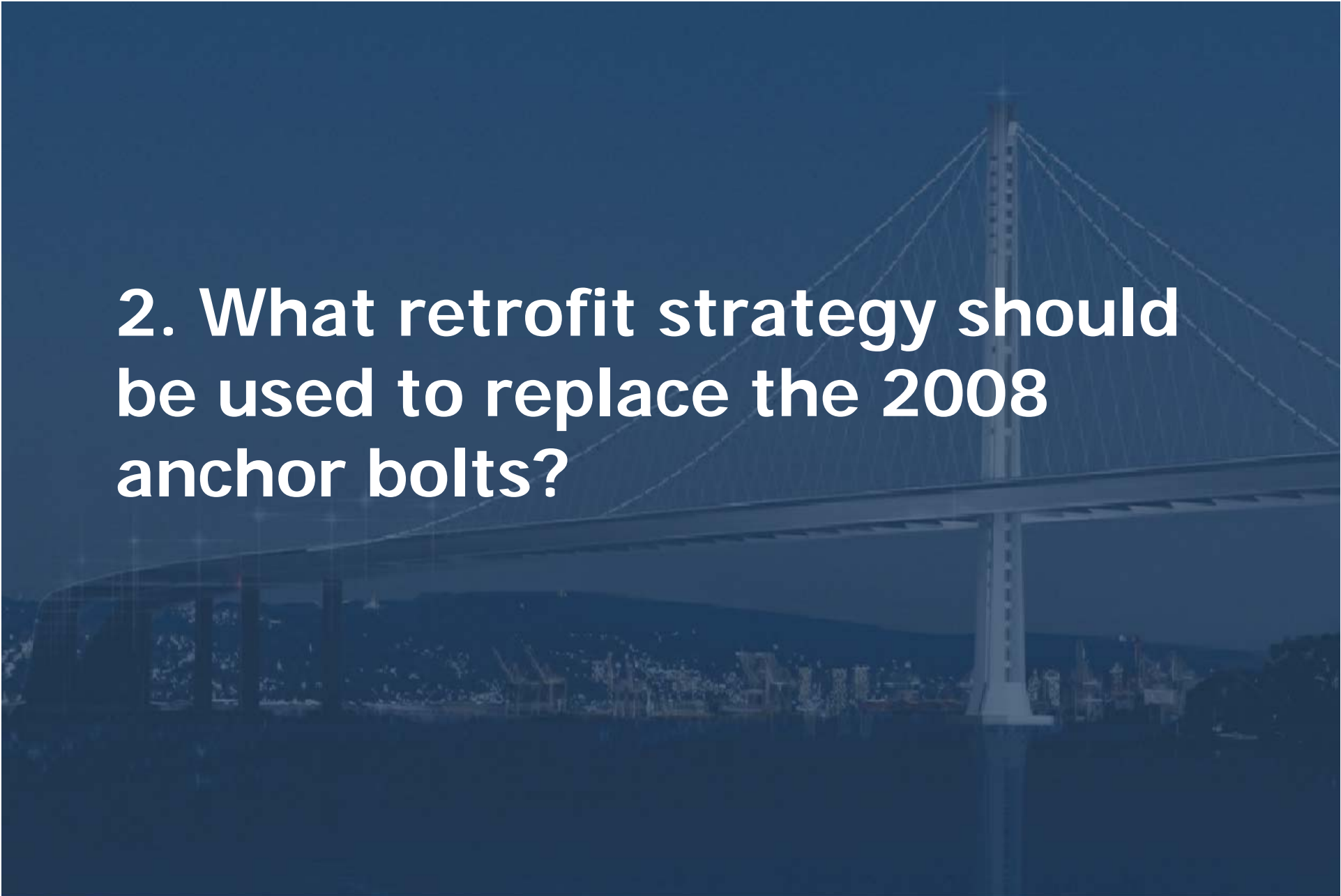
- Procurement of future A354 grade BD anchor rods should include a number of supplemental requirements to assure against hydrogen embrittlement failure.



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.

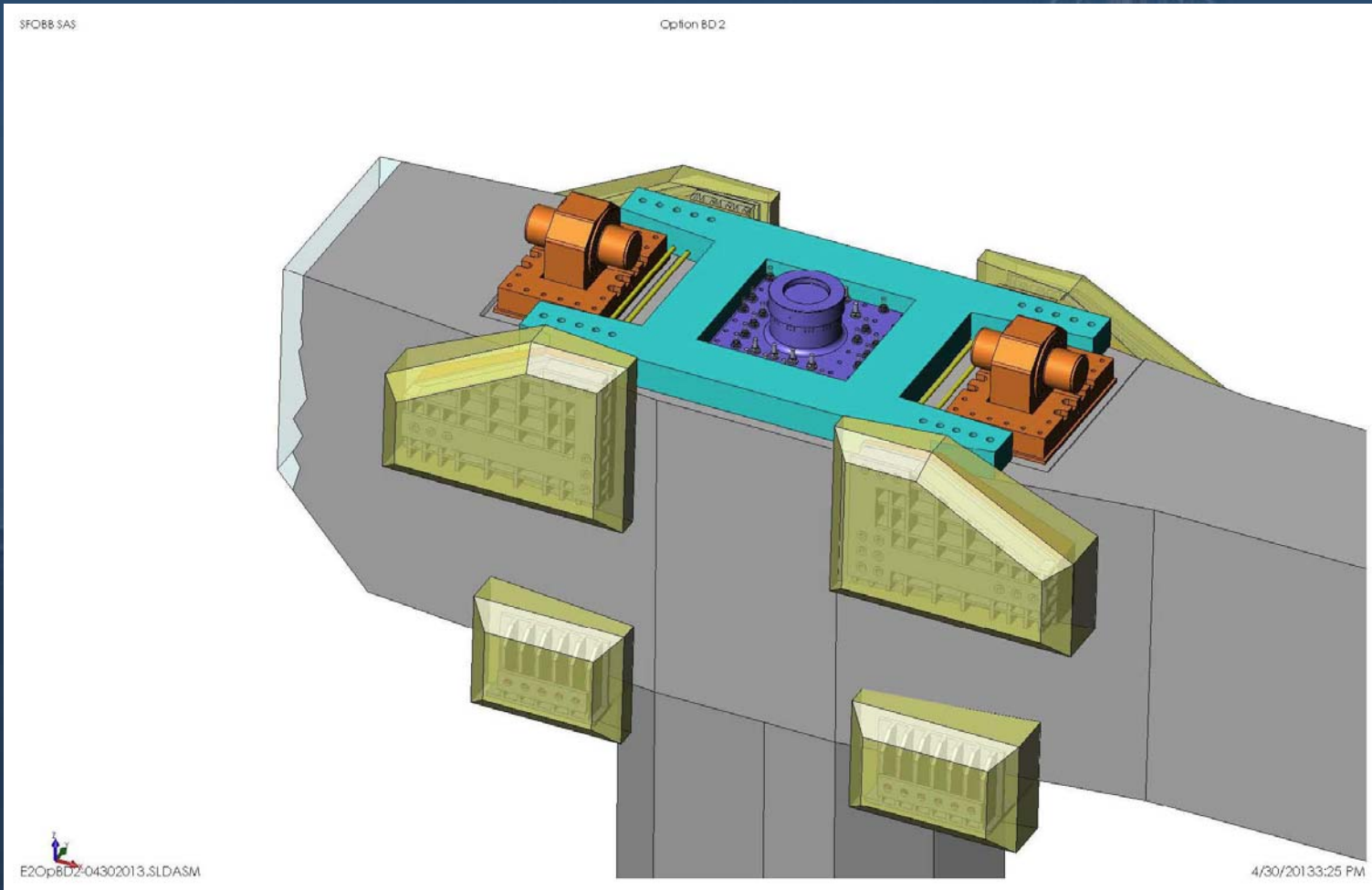




2. What retrofit strategy should be used to replace the 2008 anchor bolts?



Option 1 – Steel Collar



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
SEISMIC SAFETY PROJECT

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Option 2 – Steel Saddle



General Comparison of Options

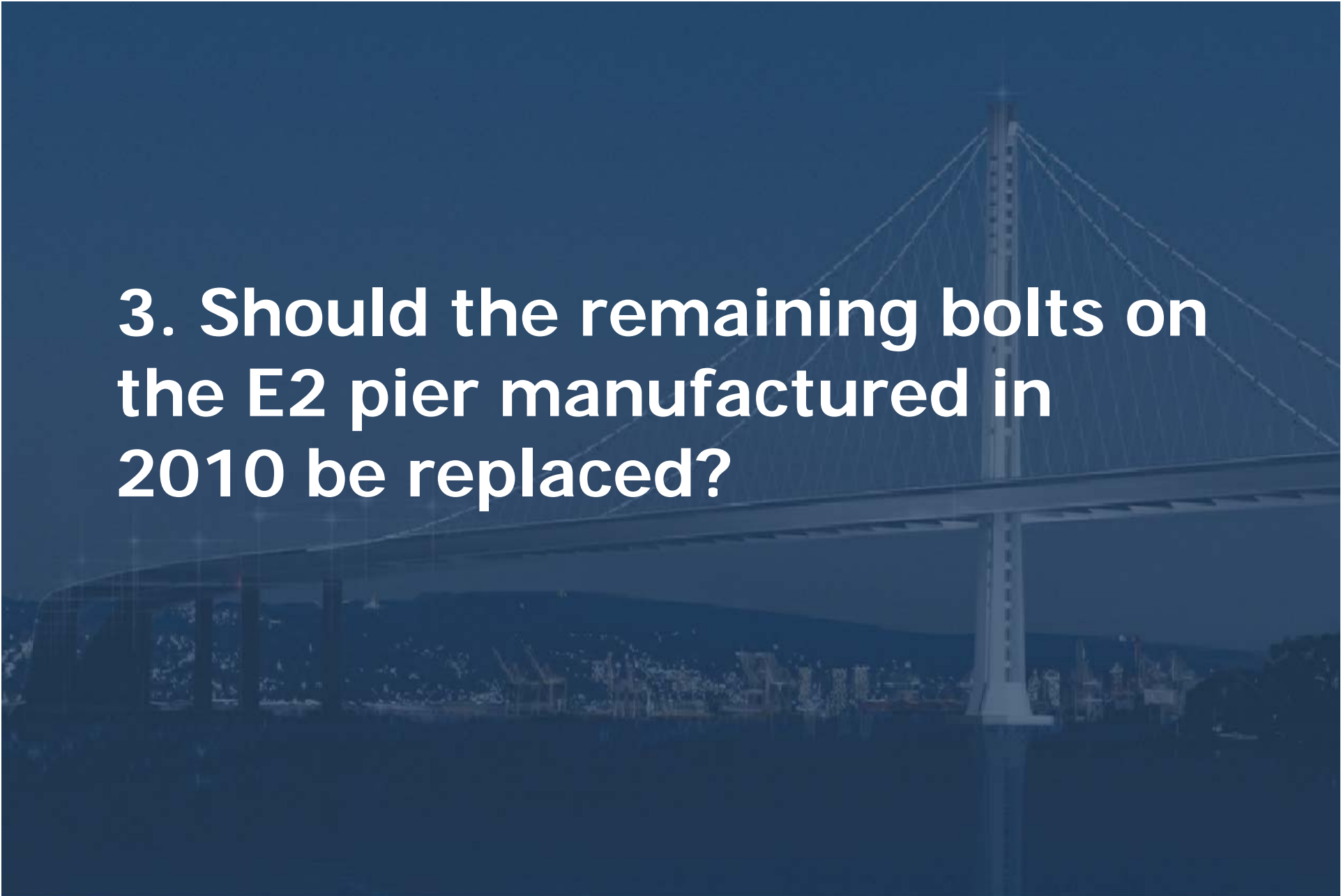
Option 1 – Steel Collar	Option 2 – Steel Saddle
<p>Pros</p> <ul style="list-style-type: none">• No need to remove S1 and S2 shear keys• Potentially simpler to fabricate	<p>Pros</p> <ul style="list-style-type: none">• No need to remove S1 and S2 shear keys• Less coring of E2 required• Potentially less difficult to install.• Less costly: \$5 to 10 m
<p>Cons</p> <ul style="list-style-type: none">• Need to find sufficient materials and resources• More coring of E2 required• More costly: \$15 to 20 m	<p>Cons</p> <ul style="list-style-type: none">• 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.



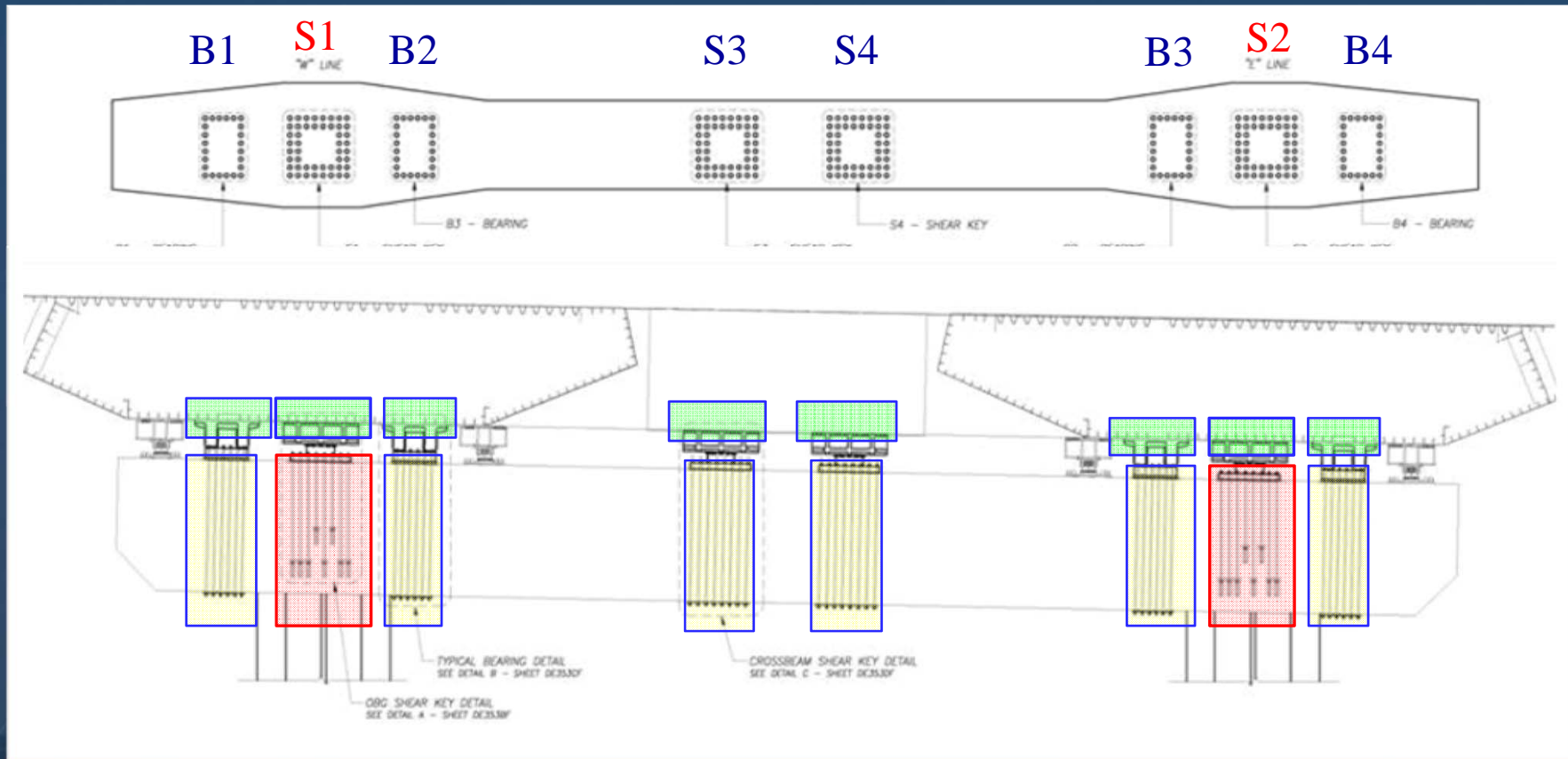


3. Should the remaining bolts on the E2 pier manufactured in 2010 be replaced?



THE SAN FRANCISCO-OAKLAND
BAY BRIDGE
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- 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 1/2"	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 = 1/4" to 2 1/2"	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.

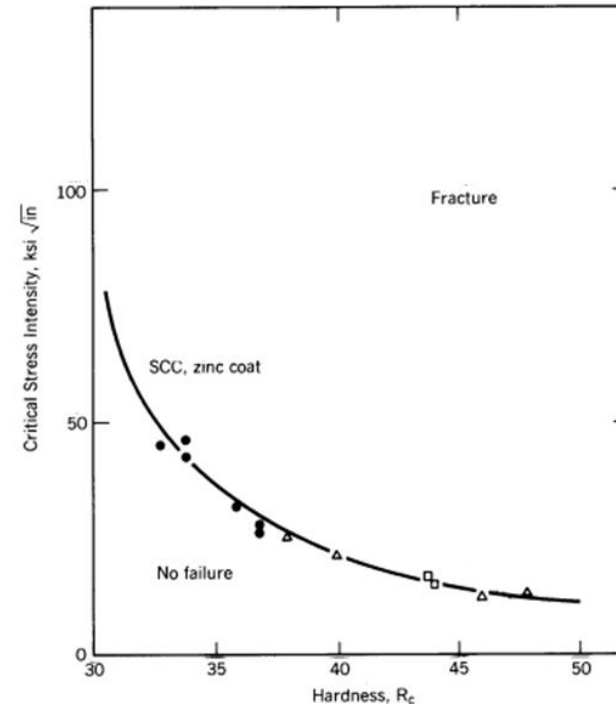


Fig 4.28. Critical Stress intensities in presence of corrosive environment;
● K_{SC} , hot-dip Al-Zn; ▲ K_{SC} , electroplated zinc; ■ K_{SC} , hot-dip zinc.

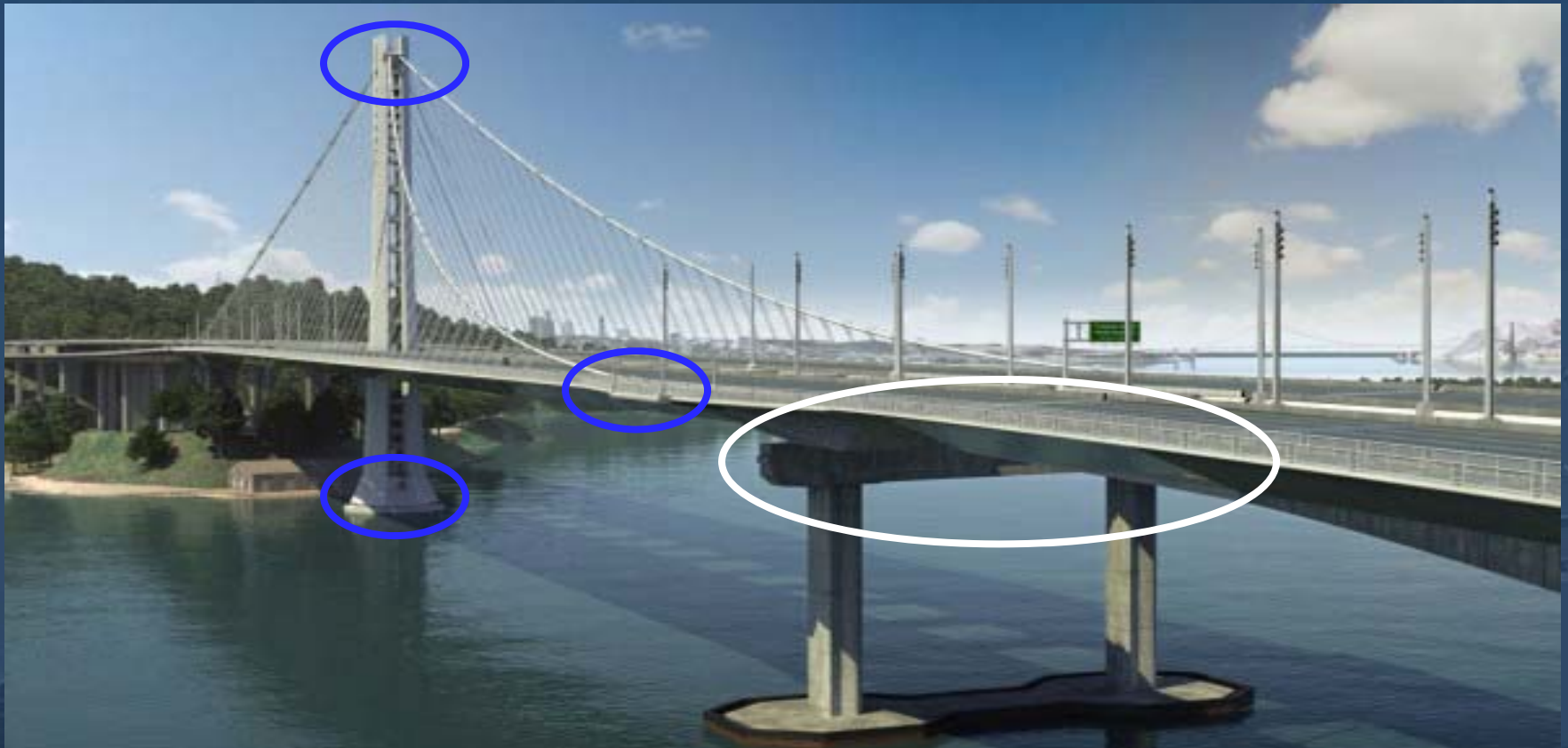
Sample Critical Stress Curve from *Guide to Design Criteria for Bolted and Riveted Joints 2nd Edition* authored by Geoffrey Kulak, John Fisher, and John Struik and published by American Institute of Steel Construction





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.

