State of California
**DEPARTMENT OF TRANSPORTATION**

Business, Transportation and Housing Agency

# Memorandum

*Flex your power!*
*Be energy efficient!*

**To:** TONY ANZIANO
Toll Bridge Program Manager

**Date:** March 29, 2013

**File:**

**From:** MALCOLM DOUGHERTY
Director

**Subject:** **BAY BRIDGE E2 CONNECTOR RODS**

In light of recent developments regarding steel rods associated with shear keys and bearings at E2 of the Self Anchored Suspension bridge, and as per conversations subsequent to discovery of the failing rods, please take the following steps to ensure the safety and successful performance of these appurtenances after completion of construction. It is acknowledged that many, if not all, of the steps iterated here have already begun.

- Put the contractor on notice in writing that they need to demonstrate that they are in compliance with contractual requirements and secure their proposed course of action.
- Initiate and conclude a complete forensic analysis to determine to the greatest extent possible the cause of the failures.
- In addition to material evaluations, determine the forces to which these rods were subjected to at time of failure.
- It is my understanding that rods associated with shear key 1 and 2 were installed in 2008, and the remaining shear key and bearing rods were installed in 2010, and that the failures thus far are all associated with the 96 rods installed in 2008 for shear key 1 and 2. Determine definitively the manufacturers and suppliers involved in delivering the rods to the job site for all rods installed.
- Articulate the testing and compliance certification process employed during construction to fulfill Quality Control/Quality Assurance efforts.
- Subject the broken rods to subsequent testing to help ascertain failure cause.
- Subject representative group of rods installed in 2010 and not yet tensioned to testing to analyze for adequate strength and properties.
- Identify any other components of the bridge that came from the same manufacturer or supplier and re-inspect.
- Once the design and construction team selects a preferred solution, present it to the Toll Bridge Program Oversight Committee (TBPOC) for approval.
- Once approved, develop cost and schedule impacts of implementing solution.

I want to reiterate that safety of the bridge once opened is the paramount and controlling factor in all decision making on this issue. We will ascertain any cost and schedule implications once the best solution consistent with the design life of the bridge and performance expectations are met. Continue to maintain a frequent dialogue with myself and other TBPOC members at all times as you are continuing to evaluate and determine best solution.

c: Brian Kelly, Acting Secretary, Business, Transportation and Housing
Andre Boutros, Executive Director, California Transportation Commision
Steve Heminger, Executive Director, Metropolitan Transportation commission

CURRENT STATUS OF E-2 HIGH STRENGTH ROD INVESTIGATION June 25, 2013

Updates appear in red text.
Complete items in green text

1. Put the contractor on notice in writing that they need to demonstrate that they are in compliance with contractual requirements and secure their proposed course of action.

Status: 4/5. To be discussed in executive session as a contract administration matter.
4/10. Notice letter sent 4/10/13. Task complete.

2. Initiate and conclude a complete forensic analysis to determine to the greatest extent possible the cause of the failures.

Status: 4/5. This has been underway for at least 3 weeks and is anticipated to be ongoing for at least another 6 weeks.
4/10. No change.
4/16. Ongoing. See items 5, 6 and 7 below.
4/22 Ongoing. See items 5, 6 and 7 below. It is the consensus conclusion of the metallurgical experts involved in the analysis that the cause is clearly hydrogen embrittlement, with the source of hydrogen possible being internal or environmental. Rod susceptibility to embrittlement was due to a lack of uniformity in the steel microstructure,
5/1. A Draft Final metallurgical analysis has been prepared.
5/14. Metallurgical report issued. Task complete.

3. In addition to material evaluations, determine the forces to which these rods were subjected to at time of failure.

Status: 4/5. Rods were jacked to 105 KSI, which resulted in a final stress of 98 KSI (the stress reduces slightly after jacking is complete and jacks are removed), or 70% or the specified tensile strength of the rod.
4/10 Task complete.

4. It is my understanding that rods associated with shear key 1 and 2 were installed in 2008, and the remaining shear key and bearing rods were installed in 2010. Also, that the failures thus far are all associated with the 96 rods installed in 2008 for shear key 1 and 2. Determine definitively the manufacturers and suppliers involved in delivering the rods to the job site for all rods installed.

Status: 4/5. The present issue involves high strength rods installed at the cap beam of Pier E-2 that are classified as ASTM (American Society for Testing and Materials) A354BD. All A354BD rods supplied for Pier E-2 were supplied by the Dyson Corporation. In addition, to address potential public questions and concern, we are assessing all other A354BD high strength rods installed on the SAS at other locations (other than E-2), all of which were supplied by Dyson. Other bolts, classified as ASTM354BC and 34CrNiMo6QT were supplied by Dyson, the Portland Bolt and Manufacturing Company and Goodwin Steel. These other bolts are unlikely to be susceptible to hydrogen embrittlement or other hydrogen related causal factors, the suspected cause of the E-2 bolt fractures. This may be modified based on the conclusion of 2 above and 6 and 7 below.
4/10 One additional supplier of A354BD rods has been identified – Vulcan Threaded Products supplied the tower anchor rods to KFM for the E2-T1 contract. A complete

list of A354BD rods/bolts, including installation locations, loading and inspection status is attached

4/16. An updated list of A354BD rods/bolts, including installation locations, loading and inspection status is attached. This list will be updated to reflect additional relevant information and additional inspection but the task of identifying suppliers for all 2008 and 2010 rods is complete.

4/22. An updated list of A354BD rods/bolts, including installation locations, loading and inspection status is attached.

5/1. An updated list of A354BD rods/bolts, including installation locations, loading and inspection status is attached.

5/14. An updated list of A354BD rods/bolts, including installation locations, loading and inspection status is attached. Note that item 8 has additional information regarding increased tension from service load – tension increases to .68 with service load.

5/22. No update to list of A354BD rods at this time. Task of identification complete.

5. Articulate the testing and compliance certification process employed during construction to fulfill Quality Control/Quality Assurance efforts.

Status: 4/5. Since the fractures in question are occurring in the rods, the focus of this response is on the rods. All 96 rods installed for shear keys 1 and 2 were manufactured in 2008. Quality control steps for these rods included the following: steel mill certification of chemical composition, independent laboratory testing of mechanical properties (yield, strength, elongation, reduction of area) of mill stock, independent laboratory testing of mechanical properties post heat treatment, and mill readings of galvanization thickness. Certifications of compliance were provided by Dyson. Quality assurance testing was performed by the Department's materials Engineering and Testing Services and included the following: pre-fabrication audits of all facilities involved in fabrication, regular inspection of facilities during fabrication, and in-house laboratory testing of mechanical properties post heat treatment and post-galvanization. Out of the 156 results obtained from both quality control and quality assurance testing; only 5 results were below specifications. All 5 involved on mechanical property – elongation. The specification requires a minimum of 14% elongation, and 5 results were in the range of 12.5-13.6%, or 1.5-0.4% below specification. These results were reviewed by design and construction and the material was determined to be suitable for use.

4/10. Documentation of the QC/QA process for fabrication of the 2008 and 2010 rods has been compiled and distributed.

4/16. Additional documentation of follow-up QC/QA related questions being compiled.

4/22. Additional documentation of follow-up QC/QA related questions is complete.

5/1. QC/QA documentation is now being collected for all E2 A354BD rods and bolts. The records will be segregated by item number as outlined in the A354BD spreadsheet referenced in #4 above. The goal is to complete this work by May 8.

5/14. Collection of mechanical test results for all items completed May 7. Associated documentation is still being collected. Documents from E2-T1 have been difficult to retrieve as METS was not integrated into the database system for that contract and manual review of paper files is required. Goal is to complete all documentation prior to May 29.

5/22. QC/QA documentation complete for items 1-11 and14-17. More documents for E2-T1 (items 12-13) have been located but manual search for some documentation still continuing. Complete binders for 1-11 and 14-17 will be produced and available for distribution by May 28 and all available documentation for items 12-13 will be included also.

5/26. Production of binders for 1-11 and 14-17 complete 5/25. Manual search for E2-T1 (items 12-13) continuing.
6/5. Manual search for E2-T1 (items 12-13) continuing.
6/25. Manual search did not locate all likely documentation. Quality control test results were previously located and incorporated into documentation package.

6. Subject the broken rods to subsequent testing to help ascertain failure cause.

Status: 4/5. One broken rod has already been subjected to 2 destructive tests, including electron microscopy. Additional destructive testing is proposed for 1 additional broken rod. 4/10. Destructive testing is being scheduled with the test facility.
4/16. Final report of initial destructive testing should be complete later this week. Additional destructive testing has been performed on a second fractured rod, and results are consistent with the first round of testing. Additional borescope evaluation is ongoing this week with water sampling where water is found. A clarification of the first two rod holes evaluated by borescope – water was found in only ONE hole.
4/22. Draft report of initial destructive testing has been prepared and final report should be complete within days. Report on additional destructive testing of second fractured rod is being prepared. Additional borescope evaluation of 2 additional holes where fractured rods were removed is complete. Standing water was NOT observed in either hole. In summary, for the 4 holes where fractured rods were removed, standing water was observed in 1 of the 4 holes.
5/1. A Draft Final metallurgical analysis has been prepared.
5/14. Final metallurgical analysis has been issued. 2 more rods will be extracted from S1-S2 and reserved in case future testing is required. This will occur this week.
5/22. Additional rods extracted and will be subjected to testing defined in testing plan.
5/26. No change.
6/5. No change.
6/25, No change.

7. Subject representative group of rods installed in 2010 and not yet tensioned to testing to analyze for adequate strength and properties.

Status: 4/5. A draft testing plan has been developed for TBPOC review and is being submitted for TBPOC review with this update report.
4/10. The TBPOC approved a testing plan and testing of the remaining 192 rods at E-2 is underway. All 192 rods are fully tensioned. 10 rods have been instrumented per plan120 rods were tensioned as of March 30, and tensioning of the remaining was completed on April 8. As of this date, no rod failures have been observed. Daily inspections are occurring.
4/16. 2010 rods are inspected daily. As of today, no fractures of the 2010 rods have been observed.
4/22. 2010 rods continue to be inspected daily. As of today, no fractures of the 2010 rods have been observed. Tensioning of these rods began on 3/30 and was complete on 4/9, so “age of tensioning” runs from 12 to 22 days. On Saturday, April 20, 2 rods were removed for early destructive testing. An additional 2 rods will be removed over the next few days, also for early destructive testing. The remaining 6 rods will be tested at the conclusion of the 30 day in-situ testing. An order for replacement rods (to replace the 10 rods to be removed for testing) has been placed with Dyson.
5/1. 2010 rods continue to be inspected daily. As of today, no fractures of the 2010 rods have been observed. Tensioning of these rods began on 3/30 and was complete on 4/9, so “age of tensioning” runs from 21 to 31 days. Surface hardness

testing of 46 rods was completed in the field on April 24 (5 locations on each rod, taken every ½ inch). The hardness data shows more consistency than seen in the 2008 rods and also lower hardness values than the 2008 rods. The average hardness was 32.7, comparable to the average of 33.4 from the in process QC/QA results from the 2010 rods). The additional 2 rods were removed and all 4 rods were subjected to destructive testing on April 26. This testing was unusual in that it involved whole rods. Preliminary data is being compiled. The fractured surfaces showed evidence of ductile fracture. The fractured surfaces and ends of 3 rods were taken to the Christensen laboratory for sample preparation on April 27. Laboratory analysis will occur from May 1 through May 7, and preliminary results may be available by May 8. The laboratory metallurgical testing performed will be analogous to the testing performed on the 2008 rods. 4 additional rods will be identified for testing after completion of the 30 day tensioning period (which will be complete on May 8). These rods will be subjected to full scale, slow strain "wet" testing to assess susceptibility to long term stress corrosion cracking. The rods will be immersed in a 3.5% salt solution, and tensioned to specified levels for set periods, with tension being gradually increased every 2 days. The test will run for a maximum of 25 days. Rods will either fracture during testing or will be fractured at the completion of testing, followed again by metallurgical testing of the fractured rods. This will require construction of test beds at Pier 7, and design of these beds is underway. Draft plans should be complete by the end of this week.

5/14. 2010 rods continue to be inspected daily. As of today, no fractures of the 2010 rods have been observed. Tensioning of these rods began on 3/30 and was complete on 4/9, so "age of tensioning" runs from 45 to 55 days. Design of Townsend ("wet") test is being modified to accommodate smaller length/diameter bolts to provide testing capacity for all A354BD fasteners. 4 additional 2010 rods have been identified and will be extracted after Townsend test beds are complete. Additional surface hardness readings will be taken from rods at B1-B4 and S4. ABF completed grinding rod tops yesterday in preparation.

5/22. 2010 rods continue to perform with no observed problems. Design of Townsend test beds finalized and transmitted to ABF. Location of 4 additional 2010 rods to be extracted for testing identified and transmitted to ABF. Surface hardness testing of all E2 2010 rods and bolts (lower and upper) is 80% complete, with readings consistent with QC/QA testing.

5/26. 2010 rods continue to perform with no observed problems. "Age of tensioning" runs from 57 to 67 days. Surface hardness testing complete at E2. Results are consistent with data from QC/QA. Preparation for surface hardness testing at tower base will begin this week. ABF is reviewing Townsend test bed design and is identifying opportunities to accelerate construction. Draft sampling rate for additional testing attached.

6/5. 2010 rods continue to perform with no observed problems. "Age of tensioning" runs from 62 to72 days. Surface hardness testing complete at E2 for exterior upper and lower rods and bolts (there are some rods only accessible from within the OBG and surface hardness testing is not complete in these areas). Grinding for surface hardness testing at tower base has started. Townsend test bed materials are being ordered and concrete pad for test beds will be poured next week. Testing spreadsheet is attached to TBPOC memo 5a2. A detailed status of Tests I, II and III, as listed in the spreadsheet, is as follows:

For Test I, II, and IV, sampling the PWS anchor rods: ABF had a single crew for half a day in the afternoon cutting PWS anchor rod stickout behind the anchorage. They made 42 of 270 cuts (16% complete). The material is still in the anchorage and will be transported out of the bridge later.

For Test II, lab test: Many of the samples, particularly the higher priority samples, come from spare rods. Some of the samples were cut this afternoon and the remainder will be cut tomorrow morning. METS will ship them to a lab tomorrow. There are still other samples that will need to be cut in the field.

For Test III, full size: The 9 (of 9) pieces were sent to Berkeley today. The nuts and washers will follow tomorrow. The 2 (of 2) pieces will be sent to Texas tomorrow. One of those pieces needed to be cut from a larger piece, and that happened this afternoon.
6/25. Tests I, II and III complete for rods/bolts at all locations. Test beds for Townsend test (Test IV) have been constructed, fabrication of beds is underway. Test result package will be presented at 6/25 meeting. In summary, results were very good in terms of distinguishing mechanical properties – average hardness values ranged from 32-34 (both field surface and lab) and Charpy toughness values were excellent in all but one case. The tower tie rods showed lower Charpy values for both machined and full size samples, in the range of 17-20. These values are considered acceptable.

8. Identify any other components of the bridge that came from the same manufacturer or supplier and re-inspect.

Status: 4/5. We will conduct a complete visual inspection of all Dyson high strength rods, including both A354BD and A354BC rods and bolts, and prepare a report of this inspection. Also see status under 4 above.
4/10. All A354BD rods and bolts from all suppliers have been inspected visually, and regular reinspections are occurring. See attached summary. Note that a few locations are inaccessible.
4/16. Initial visual inspection is complete. Reinspection will occur on a 1-2 week cycle until the overall evaluation of the E2 rods is complete.
4/22. A second reinspection occurred 4/20-21. All rods are in good condition.
5/1. An updated list of A354BD rods/bolts, including installation locations, loading and inspection status is attached.
5/14. Surplus material (extra rods and bolts not used but from same material lots as rods and bolts actually installed) has been identified and stored for possible testing. Townsend testing of other A354BD rods and bolts may be conducted. One rod from the tower foundation pile cap has been extracted for testing, including Townsend testing. . Additional surface hardness testing will be performed and ABF completed grinding rod tops of all upper bolts at E2 yesterday in preparation.
5/22. Next visual reinspection scheduled for this weekend.
5/26. Bi-weekly visual reinspection completed. No problems observed.
6/5. No change.
6/25. Bi-weekly inspections continuing with no observed problems. Next inspection scheduled for the coming weekend.

9. Once the design and construction team selects a preferred solution, present to the Toll Bridge Program Oversight Committee for approval.

Status: 4/5. Daily discussions have been ongoing between the prime contractor, the design joint venture and Department staff regarding development of a design solution for the S1 and S2 shear key attachments. A final design is weeks away, but focus is currently on a steel collar alternative secured to the cap beam with high strength rods that fully penetrate the cap beam.

4/10. Design development is continuing. A meeting between the TBPOC, TY Lin/MN and ABF has been scheduled for April 17 to discuss status of alternative development.
4/16. Design development is continuing and evolving on a daily basis. Current alternative concepts will be presented to the TBPOC on 4/17
4/22. Design alternatives were presented to the TBPOC on 4/17. A group decision was made to eliminate Alternative A. Goal is to complete design to a 65% level by April 30, Steel plate had been ordered for Alternative B, and ABF has selected XKT as the steel fabricator. XKT is local (Vallejo-Mare Island) and has performed steel fabrication for various elements of the East Span project.
5/1. Design has proceeded to unchecked 65%, and a matrix of design options will,be presented to the TBPOC on 5/1.
5/14. TBPOC approved Alternative C on 5/1. Design checking is underway and ABF has started work on surface preparation (concrete chipping) at E2.
5/22. ABF has started work on access (work platforms) at E2. Core drilling for transverse Post tensioning tendons will begin 5/23.
5/26. Core drilling ongoing below Shear Key 1.
6/5. Core drilling 95% complete (20 of 21 holes), and will be complete tomorrow. Dowel drilling, westbound/east face complete.
6/25. Drilling of shear keys ongoing. Saddle plate cut by XKT and material that will be processed by Steward has been delivered. XKT has started rolling of cut plate.

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10. Once approved, develop cost and schedule impacts of implementing solution.

Status; 4/5. As requested, this will occur once a final design has been developed and priced. 4/10. Estimated costs for advance purchasing of materials for multiple alternatives will be presented on April 11.
4/16. Estimated costs were presented on 4/11. However, since design continues to evolve, detailed estimates cannot be completed.
4/22. No change.

5/1. Preliminary costs estimates, based on the unchecked 65% design, will,be presented to the TBPOC on 5/1.
5/14. Preliminary costs estimates, based on the unchecked 65% design, were presented to the TBPOC on 5/1. Schedule is under development with ABF.
5/22. Final plan check (100% design) should be complete within 2-4 days. Plans will then be transmitted by ABF to fabricator for pricing and schedule. Given design-build nature of process, design iterations are anticipated.
5/26. Plans have been submitted to fabricator for schedule and pricing.
6/5. No change
6/25. No change.