New Bay Bridge Anchor Rod Problems

Public Forum? Tech Exchange?

Tech Briefing?

February 26, 2014
I never learned from a man [or a Woman] who agreed with me –
Robert Heinlein

Engineers can do anything -
given enough money - A Journalist
Obfuscate – verb

to make (something) more difficult
to understand – CC Times

Crappy - adjective

of extremely poor quality

eexample: Crappy Steel - 2008 Rods

- TBPOC Consultant
I am Yun Chung, Mat’ls Engineer (Used to be)

• TBPOC Report is Unacceptable as an Engineering Report/Public Document
  It must be redone!!!
  I will tell you why

• Request for anchor rod samples (from soon to be scrap metal)
  Will produce a metallurgical report
  With Lab Data useful for TBPOC-Caltrans, …
Report on the A354 Grade BD High-Strength Steel Rods on the New East Span of the San Francisco-Oakland Bay Bridge
With Findings and Decisions

July 8, 2013
HIGH STRENGTH STEEL
ANCHOR ROD PROBLEMS ON
THE NEW BAY BRIDGE
MAIN CONCERNS AND RESOLUTIONS
FOR FRACTURE-CRITICAL ANCHOR RODS
ON THE NEW BAY BRIDGE
MAIN CONCERNS AND RESOLUTIONS FOR FRACTURE-CRITICAL ANCHOR RODS ON THE NEW BAY BRIDGE

December 30, 2013

Fracture-critical Anchor Rod Locations

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Berkeley Research Company
Berkeley, California
<table>
<thead>
<tr>
<th>Conclusions – wROng!</th>
<th>Why?</th>
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<tr>
<td>Inconsistent with the failure pattern</td>
<td>Can’t Explain what happened</td>
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<td>Obfuscated by &quot;inventing&quot; new terminology</td>
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<table>
<thead>
<tr>
<th>200 errors and</th>
<th>Why?</th>
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<tr>
<td>questionable statements</td>
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Over 40 errors

metallurgically UNTENABLE
Self-Anchored Suspension (SAS) Bridge

One Tower T1
One Cable
Two Piers E2, W2

#7 PWS Anchor Rods, Splay Chambers
Splay chambers - 137 bundles and 274 anchor rods, 3½” φ, 219 rods rolled threads
Saddle, top of Tower

Item #8 - 4”\(\Phi\) Saddle Tie Rods, rolled threads, 0.68\(\text{Fu}\)
One Cable Holding Decks - Hanging Basket

Items #8
Saddle Tie Rods
25 - 4”φ ~17.5’

Items #7
PWS
274 - 3½”φ ~ 32’

Items #12, 13
Tower anchor rods
388 - 3”φ x 25.6’
36 - 4”φ x 25.7’
(a) SAS Bridge
(b) Shear Key S1
(c) Anchor rods on S1 base plate
(d) The cap beam of Pier E2 with the anchor rod failure location illustrated
All 32 failures occurred in the bottom.
Conclusions: Anchor Rods Failed due to HE  OK!
(1) **Stress** – from Pretension 0.7Fu  OK!
(2) **Hydrogen** – “that was present and already available in the rod …”  ???

- Internal hydrogen embrittlement (IHE) or
- Environmental HE (EHE) - Not Clarified

(3) **Root Cause** – Higher than **normal** susceptibility of the steel to HE  NORMAL?

(4) **Metallurgical Conditions** – less than **ideal**  
**Ideal?** – undefinable!
Not a Specification lingo!!!
Hydrogen embrittlement cracking

● Internal Hydrogen Embrittlement (IHE)

● Environmental Hydrogen Embrittlement (EHE)

TBPOC Report Invented a new name:

EHE $\rightarrow$ Longer-Term Stress Corrosion Cracking (SCC)
A Key Question not Answered:

Why 32 Rods Fail \textbf{all} in the Bottom Threads?

Probability of bottom failure = 0.5 per rod

\[ P(B) \text{ of 32 rods bottom failures} = (0.5)^{32} \]

\[ = 2.33 \times 10^{-10} \text{ or } <1:4,000,000,000,000. \]

Odds of 32 failures all in the bottom
Less than one in four billion

Dying by lightning strike: 1:6,250 in 80 yr life
Anchor rods were installed only for Shear Keys S1 and S2.
Critical Stress Intensity vs. Surface Hardness
Townsend Formulation
(Based on Rod by Rod Data from Test 1: June 21, 2013)

7/10/13 BATA Briefing, by Caltrans Director
Figure 34: Critical Stress Intensity as Compared to Surface Hardness
With In-situ Surface Hardness Test Data

2 - 5 errors

1. 33 – 41 HRC for BD

2. Item #8: 4" bolt (0.68 Fu)
3. Item #2, 3: 3" bolt (0.70 Fu)
4. Item #4: 2" bolt (0.70 Fu)
5. Item #9: 3-1/16" bolt (0.45 Fu)
6. Item #12: 3" bolt (0.48 Fu)
7. Item #13: 4" bolt (0.37 Fu)
8. Item #7: 3-1/2" bolt (0.32 Fu)
9. Item #5: 1" bolt (0.61 Fu)
10. Item #15: 3" bolt (0.30 Fu)
11. Item #6: 1" bolt (0.40 Fu)
12. Item #16: 3" bolt (0.16 Fu)
13. Item #10, 11: 3" bolt (0.10 Fu)
14. Item #14: 2" bolt (0.10 Fu)

4. Will fail 140 ksi min TS (Tensile Strength)
5. Impossible!
3. May fail 140 ksi min TS

Will fail 140 ksi min TS
Figure 33 Determination for Susceptibility to Stress Corrosion Cracking

Testing of A354 Grade BD High-Strength Steel Rods Used on the SAS Bridge

Test I: In-Situ Hardness Test
Test II: Lab Test
Test III: Full-Size Test
Test IV: Townsend Test
Test V: Raymond Test

Categorize Rods by Hardness
Determine Mechanical & Chemical Properties of Rods
Determine Susceptibility Threshold to SCC

Analyze Data

Plot Each Rod on the Townsend SCC Curve Using Individual Stress Intensity & Hardness at Surface Values

Not Susceptible to SCC
To Left
Location to the Townsend SCC Curve
To Right
Susceptible to SCC

Can Tension of Exposure to Corrosion Be Reduced?

Ongoing Monitoring
Reduce Tension
Improve Corrosion Protection, Including Dehumidification
Replace After Bridge Opening
### Examples of Bloopers

#### Summary Results of Testing for Susceptibility to SCC

<table>
<thead>
<tr>
<th>Item #</th>
<th>Microstructure</th>
<th>HRC</th>
<th>Surface Hardness of Tested Rods (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Incomplete martensitic</td>
<td><strong>36.9</strong> (avg)</td>
<td>36.9 – 38.2 (min – max)</td>
</tr>
<tr>
<td></td>
<td>Shear Key Anchor Rods (2008)</td>
<td></td>
<td>(Metallurgical Report)</td>
</tr>
<tr>
<td>#2</td>
<td>Essentially martensitic</td>
<td><strong>29</strong> (avg)</td>
<td>29 – 39.3</td>
</tr>
<tr>
<td></td>
<td>Bearing &amp; Shear Key Anchor Rods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td>Essentially martensitic</td>
<td><strong>25.1</strong> (avg)</td>
<td>25.1 – 38.9 (min – max)</td>
</tr>
<tr>
<td></td>
<td>Parallel Wire Strands (PWS) Anchor Rods</td>
<td></td>
<td></td>
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</tbody>
</table>
### Examples of Bloopers

<table>
<thead>
<tr>
<th>Mode of Fracture</th>
<th>CVN toughness</th>
<th>Sustained Applied Tension</th>
<th>Secondary corrosion protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Brittle</td>
<td>CVN 13 - 14</td>
<td>13.5 (avg)</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 - 14</td>
<td>N/A</td>
</tr>
<tr>
<td>#7 Ductile</td>
<td>CVN 13 – 18.5</td>
<td>16.8 (avg)</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 – 18.5 (min - max)</td>
<td>Dehumidifie</td>
</tr>
<tr>
<td>#8 Ductile</td>
<td>CVN 11 – 54</td>
<td>32.7 (avg)</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.5 – 54 (min - max)</td>
<td>Dehumidifie</td>
</tr>
</tbody>
</table>
Fracture Face Interpretation by Caltrans

Improved Microstructure

Failed 2008 Rod

Brittle Failure in Field

S1G1

Other Rod

Ductile Failure in Lab Test

1. Initiation
2. Propagation
3. Final fracture
4. Crack initiation
5. Crack growth

Bay Bridge Seismic Safety Project
Fracture Propagation Directions – Lab test
No micro-structural examination can determine the presence of hydrogen.
Examples Of Bloopers during Caltrans/TBPOC Presentations

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.

Typical Hardness Profile of LAQTS

30 HRC 138 ksi
35 HRC 156 ksi

39 HRC 177 ksi

Tensile Specimen

R = 1.50"

r/2 = 0.75"

3" 4140 Q&T
Field - Lab Hardness Test Data

Reliable or Possible for 4140 Q&T?

7-II-W-066
PWS Anchor Rod
3.5”φ x 28 - 32’

Rolled Threads?

0.5” from Surface

35HRC

Field
Laboratory
+ ASTM Req.
Hardness data Tower Saddle Tie Rod
Item #8, 4” ϕ Heat Treated, Rolled Threads
0.68 Fu Tension
Lab Hardness Test Data

Reliable or Possible for 4140 Q&T?

12-II-W-60

Tower Base
3.0”Ø x 26’

35HRC

0.5” from Surface
Lab Hardness Test Data
Reliable or Possible for 4140 Q&T?

13-II-cE-9
Tower Base
4.0” φ x 26’

HRC

Rockwell C Hardness

0.5” from Surface

35HRC

Field
Laboratory
ASTM Req.
Questions to TBPOC-Caltrans and Consultants

- Explain why all 32 failures occur in the bottom threads and none in the top threads
- Explain the errors in Fig. 33 and 34
- Explain the objectives of the Townsend Test
- Explain the uncertainties in the SCC prevention methodology using KI_{scc}/HRC data
Dear Mr. Chung:

Your most recent October 31st email alleges “177 errors and questionable statements”

[They are ] “purported errors” “quibbles over terminology” e.g., EHE vs L-T SCC

“unsupported assertions”

“inconsequential matters”

“You are manufacturing a disagreement where there is none”
Report on the A354 Grade BD High-Strength Steel Rods on the New East Span of the San Francisco-Oakland Bay Bridge, With Findings and Decisions

July 8, 2013
The TBPOC Report with numerous errors is unacceptable. They are neither “purported errors” nor “inconsequential matters.”

TBPOC-Caltrans must issue a new report on the cause of the S1 and S2 anchor rod failures and remedial measures.
3 million rivets

28° - 31°F

Water temp

Titanic
Was Titanic a weak ship? Sank in 2.7 hrs. No. She saved 705 lives?
Is the SAS a New Titanic?
Was it the crappy steel?
like
the crappy rivets?
No!!! It was due to …