Agenda- Various SAS Test Results Progress Update

1. Townsend Test IV results- 12/31/13 Book-
2. Progress on Lou Raymond Test V
   a. Review Raymond Results sheets 1-4
      i. Kic vs Hardness sheet 4 of 4
      ii. Kiscv vsa Hardness sheet 3 of 34
      iii. K IHE vs Hardness sheet 2 of 4
      iv. Fast Fracture sheet 1 of 4
   b. Review Test Specimens- Pre-crack and Root of thread
   c. Review Green, Yellow, Red Stress Intensity vs Hardness qualitative curves
3. Mantle question regarding “2008 lower Rod ends were in water”
   a. Mantle E-mail
   b. TBPOC Rod Location sheets
   c. Photographs of 2008 rod ends
   d. Top Hat- Quick Video Look at Rod Bottom
   e. Boroscope snag-it photographs
   f. “Staged” 2008 lower rod end findings from review of boroscope videos
   g. Common Factor
h. Gorman Draft Response to Mantle e-mail

4. Electro Lag Update
   a. Photograph of Sample
   b. NOPC Draft Department Letter
POST FRACTURE ANALYSIS
TEST RESULTS

S3-D2
Dry Specimen

Hot-dipped coating morphology observed. Numerous cracks in the intermetallic layer observed extending into the base metal. Areas of coating delamination observed and tips have minimal to no coating.

Crack extends through coating into base metal. Oxide observed in cracks in coating and steel.

S3-D2
Wet Specimen

Hot-dipped coating morphology observed. Numerous cracks in the intermetallic layer observed extending into the base metal. Areas of coating delamination observed and tips have minimal to no coating.

Crack extends through coating into base metal. Oxide observed in cracks in coating and steel.

Outermost Coating

Innermost Coating

Oxide in Steel

Oxide in Crack
Fracture Toughness of the Core Material $K_{\text{max}}$ and Effective Fracture Toughness $K_p$ of the Threads

<table>
<thead>
<tr>
<th>ID</th>
<th>Structural Component</th>
<th>Dia.</th>
<th>Sample</th>
<th>Comment</th>
<th>Fast Fracture Strength $K_{\text{cle}} = K_{\text{c}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Center $K_{\text{cle}}$</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top (B1/S2)</td>
<td>3&quot;</td>
<td>3-V-8</td>
<td>Same Heat as ID 2 (Rod #1 through #4 Test IV)</td>
<td>36.6 HRC</td>
</tr>
<tr>
<td>1</td>
<td>Shear Key Anchor Bolts-Bottom (B1/S2)</td>
<td>3&quot;</td>
<td>1-V-62-A2-A</td>
<td>2008 at Top (Live End)</td>
<td>141.3</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts-Top Housing (B1, 152, B3, B4)</td>
<td>2&quot;</td>
<td>4-V-1</td>
<td>Rolled Threads; Same as Test Rif #6 in Test IV</td>
<td>161.3</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top</td>
<td>3&quot;</td>
<td>3-V-10</td>
<td>Same Heat as ID 2 (Rod #1 through #4 Test IV)</td>
<td>36.6 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top</td>
<td>3&quot;</td>
<td>3-V-11</td>
<td>Same Heat as ID 2 (Rod #1 through #4 Test IV)</td>
<td>36.6 HRC</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts-Top Housing (B1, 152, B3, B4)</td>
<td>2&quot;</td>
<td>4-V-2</td>
<td>Rolled Threads; Same as Test Rif #6 in Test IV</td>
<td>161.3</td>
</tr>
<tr>
<td>12</td>
<td>Tower Anchorage Anchor Bolts (75 Dia. Anchor Bolts)</td>
<td>3&quot;</td>
<td>12-V-b2E-4</td>
<td>Cut Threads</td>
<td>36.6 HRC</td>
</tr>
</tbody>
</table>

**Legend**
- **MR** = Fatigue Pre-Cracked Mid Radius Specimen
- **OD** = Fatigue Pre-Cracked OD Specimen
- **Center** = Fatigue Pre-Cracked Center Specimen
- **FFS** = Fast Fracture Strength - performed at ASTM E8 test strain rates. For uncracked specimens value recorded is estimate for $K_{\text{c}}$ from $K_{\text{c}}$ calculated from ASTM F1290-1996.
- **EHE** = External Hydrogen Embrittlement - RSL tested in salt water with potential to simulate galvanic charging with HDG-zinc coating.

**Conclusions**

<table>
<thead>
<tr>
<th>Conclusion</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C.1</strong></td>
<td>The fracture toughness of the 2008 rods are clustered around 160 ksi/ln, except rod 3-V-12 (in yellow) which has a value of around 110 ksi/ln.</td>
</tr>
<tr>
<td><strong>a.</strong></td>
<td>Further evaluation of rod 3-V-12 is being performed.</td>
</tr>
<tr>
<td><strong>C.2</strong></td>
<td>The fracture toughness of the 2008 rods is approximately 125 ksi/ln.</td>
</tr>
</tbody>
</table>

**KI-cod-fpc vs HRC 2008 & 2010**

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*Update for 02/07/2014 Meeting*
Fracture Toughness of the Core Material $K_{\text{max}}$ and Effective Fracture Toughness $K_p$ of the Threads

<table>
<thead>
<tr>
<th>ID</th>
<th>Structural Component</th>
<th>Dia.</th>
<th>Sample</th>
<th>Comment</th>
<th>EHE Testing in 3.5% NaCl charged at 1.106 Vce</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fatigue Pre-Cracked (fpc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Threaded</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MIR EHE</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top (51/52)</td>
<td>3&quot;</td>
<td>S-V-6</td>
<td>Same Heat as ID 2 (Rods 61 through 64 Test IV)</td>
<td>27.0 HRC</td>
</tr>
<tr>
<td>1</td>
<td>Shear Key Anchor Bolts-Top (51/52)</td>
<td>3&quot;</td>
<td>1-V-2-A2-A</td>
<td>2008 at Top (Live End)</td>
<td>34.0 HRC</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts-Top Housing (81,82,83,84)</td>
<td>2&quot;</td>
<td>4-V-1</td>
<td>Rolled Threads; Same as Test Rig #5 in Test IV</td>
<td>36.5 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top</td>
<td>3&quot;</td>
<td>S-V-10</td>
<td>Same Heat as ID 2 (Rods 61 through 64 Test IV)</td>
<td>33.0 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top</td>
<td>3&quot;</td>
<td>S-V-11</td>
<td>Same Heat as ID 2 (Rods 61 through 64 Test IV)</td>
<td>33.0 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top</td>
<td>3&quot;</td>
<td>S-V-12</td>
<td>Same Heat as ID 2 (Rods 61 through 64 Test IV)</td>
<td>38.0 HRC</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts-Top Housing (81,82,83,84)</td>
<td>2&quot;</td>
<td>4-V-2</td>
<td>Rolled Threads; Same as Test Rig #6 in Test IV</td>
<td>35.0 HRC</td>
</tr>
<tr>
<td>12</td>
<td>Tower Anchorage Anchor Bolts (75 Dia. Anchor Bolts)</td>
<td>3&quot;</td>
<td>12-V-v2E-4</td>
<td>Cut Threads</td>
<td>37.4</td>
</tr>
</tbody>
</table>

**Legend**
- MIR = Fatigue Pre-Cracked Mid Radius Specimen
- OD = Fatigue Pre-Cracked OD Specimen
- threaded = Threaded Specimen
- Testing needed or in progress at slower step loading rate to determine the threshold $K_{\text{fisc}}$ or $K_{\text{pisc}}$
- Invariant minimum threshold determined by two tests with one at slow strain rate per F1024. Invariant if measured values within 5% of F3. Invariant if slow stress intensity $= K_{\text{fisc}}$ or $K_{\text{pisc}}$
- EHE = External Hydrogen Embrittlement- RSL Tested in salt water galvanic potential to simulate galvanic charging with HDG-zinc coating

**Conclusions / Comments**
Preliminary, subject to change (Note: Limited to small sample size of initial test results)

C.1 $K_{\text{isc}}$ 2008 rod slightly lower than 2010 rod, with lower scatter of Townsend Curve for $V_{\text{isc}}$
C.2 $K_{\text{isc}}$ 2010 is < 40% higher than 2008, and all in the load range of 0.7 Fu.
LRA recommends we consider:
R.1. Reduce fpc EHE testing for $K_{\text{isc}}$ Zinc Potential, and initiate fpc EHE testing at rod potential.

Update for 02/07/2014 Meeting
### Fracture Toughness of the Core Material Kmax and Effective Fracture Toughness Kp of the Threads

<table>
<thead>
<tr>
<th>ID</th>
<th>Structural Component</th>
<th>Dia.</th>
<th>Sample</th>
<th>Comment</th>
<th>IHE Testing in Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fatigue Pre-Cracked (Ipc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MR IHE</td>
</tr>
<tr>
<td>1</td>
<td>Shear Key Anchor Bolts-Top (S1522)</td>
<td>3&quot;</td>
<td>1-V-S2-A2-A</td>
<td>2006 at Top (Live End)</td>
<td>35.8 HRC</td>
</tr>
<tr>
<td>2</td>
<td>Shear Key Anchor Bolts-Top (S1522)</td>
<td>3&quot;</td>
<td>3-V-8</td>
<td>Same Heat as ID 2 (Rods #1 through #4 Test IV)</td>
<td>35.8 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Pier E2 Bearing Boots-Top Housing (S182,83,84)</td>
<td>2&quot;</td>
<td>4-V-1</td>
<td>Rolled Threads; Same as Test Rig #6 in Test IV</td>
<td>35.0 HRC</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Boots-Top Housing (S182,83,84)</td>
<td>3&quot;</td>
<td>3-V-10</td>
<td>Same Heat as ID 2 (Rods #1 through #4 Test IV)</td>
<td>35.0 HRC</td>
</tr>
<tr>
<td>5</td>
<td>Tower Anchorage Anchor Bolts (75 Dia. Anchor Bolt)</td>
<td>3&quot;</td>
<td>12-V-b2E-4</td>
<td>Cut Threads</td>
<td>35.0 HRC</td>
</tr>
</tbody>
</table>

**Legend**
- **MR** = Fatigue Pre-Cracked Md Radius Specimen
- **OD** = Fatigue Pre-Cracked Od-Specimen
- **Threaded** = Threaded Specimen

- **Kmax** = Maximum K measured is greater than 95% of Kmax from FFS test indicating the IHE threshold greater than value shown.
- **FFS** = Fatigue Fracture Strength - performed at ASTM E8 test strain rates. For threaded specimens value recorded is an estimate for Kic from KicTab. Kmax is the minimum value of the load of IHE/IHE RSL test.
- **IHE** = Internal Hydrogen Embrittlement - RSL Tested in Air to detect the effect of hydrogen present from processing.
- **EHE** = External Hydrogen Embrittlement - RSL Tested in Air to determine potential to simulate galvanic charging with HDG-zinc coating.

**Conclusions / Comments**
Preliminary, subject to change (Note: Limited to small sample size of initial test results)

**Conclusions:**
- Based on this limited data, neither the 2005 nor the 2010 specimens tested exhibit IHE. However, there was concern expressed that process H2 could have diffused out of the uncoated surfaces of samples since the rod samples were removed from bridge and in storage at room temperature for up to 18 months before testing.

**LRA recommends the following:**
- Reconsider continuing IHE testing on rods in stock at LRA.
- Re-evaluate specimen preparation protocol to determine if H2 present due to manufacturing in 2010 rods.

*Update for 02/07/2014 Meeting*
Fracture Toughness of the Core Material Kmax and Effective Fracture Toughness Kp of the Threads

<table>
<thead>
<tr>
<th>ID</th>
<th>Structural Component</th>
<th>Dia.</th>
<th>Sample</th>
<th>Comment</th>
<th>Fast Fracture Strength Kmax</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fatigue Pre-Cracked (fpc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Center Kmax</td>
</tr>
<tr>
<td>1</td>
<td>Shear Key Anchor Bolts-Top (81/82)</td>
<td>3&quot;</td>
<td>1-V-S2-A2-A</td>
<td>2008 at Top (Live End)</td>
<td>31.8 HRC</td>
</tr>
<tr>
<td>2</td>
<td>Pier E2 Bearing Bolts- Top Housing (B1,B2,B3,B4)</td>
<td>2&quot;</td>
<td>4-V-1</td>
<td>Rolled Threads; Same as Test Rig #5 in Test IV</td>
<td>33.6 HRC</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts-Top (81/82)</td>
<td>3&quot;</td>
<td>3-V-10</td>
<td>Same Heat as ID 2 (Rods #1 through #4 Test IV)</td>
<td>28.6 HRC</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts- Top Housing (B1,B2,B3,B4)</td>
<td>2&quot;</td>
<td>4-V-2</td>
<td>Rolled Threads; Same as Test Rig #5 in Test IV</td>
<td>32.5 HRC</td>
</tr>
<tr>
<td>12</td>
<td>Tower Anchorage Anchor Bolts (75 Dia. Anchor Bolts)</td>
<td>3&quot;</td>
<td>12-V-b2E-4</td>
<td>Cut Threads</td>
<td>30 HRC</td>
</tr>
</tbody>
</table>

Legend:
- MR = Fatigue Pre-Cracked Mid Radius Specimen
- OD = Fatigue Pre-Cracked OD Specimen
- Center = Fatigue Pre-Cracked Center Specimen
- Threaded = Threaded Specimen
- >99.9 = For FFS of threaded specimens indicates no cracking detected at maximum K; otherwise crack initiation was detected before reaching the maximum.
- FFS = Fast Fracture Strength - performed at ASTM 88 load test rates. Values shown are the stress intensity factor for the maximum load, or Kmax. Kmax is the maximum value of the K of the IHE/EHE RBL test.
- IHE = Internal Hydrogen Embrittlement - RBL Tested in Air to determine effect of hydrogen present from processing
- EHE = External Hydrogen Embrittlement - RBL Tested in hot water with potential to simulate galvanic changes with H2O-zn-plated

Conclusions/Comments: Preliminary, subject to change (Note: Limited to small sample size of initial test results)

C.1 Kmax is calculated from the maximum load achieved in FFS (for the specimen).

Update for 02/07/2014 Meeting
2. Critical Stress Intensity

- Galvanic Corrosion
- Surface Rust/Oxidation
- SCC

When rod is tensioned one or more times above this threshold, the base material is prone to SCC and makes it susceptible to hydrogen attack.

Galvanic Corrosion can occur in zinc-iron inter-metallic layers.

No Galvanic Corrosion

No SCC

Possible Surface Rust/Oxidation

Hardness
Critical Stress Intensity

Hardness

Additional corrosion protection is essential

Good additional Corrosion protection is essential to arrest or delay SCC

Galvanic coating No longer effective due to breaches/holidays

Additional corrosion protection is not essential

Galvanic coating will give some surface protection
Ted,

I am forwarding this email to you for your information. I won’t do anything in response to it until I receive direction from you. However, getting more information on a couple of the points that Mantle raises would be useful, and you might want to talk to Caltrans about doing so:

1) Assembling a documented story regarding the sequence of grouting and tensioning for the 2008 bolts so as to be able to better assess whether grout in the washer to nut interface could have contributed to the failures. Assembling this history may already have been done but, if so, I am not aware of where it located.
2) Assembling a documented story with photos of the conditions of zinc coating at the lower ends of the failed 2008 rods to determine if the coating shows signs of penetrations that could have allowed ingress of hydrogen. Thus far, all I am aware of regarding such documentation is the observation in the metallurgical failure analysis report (the ABC report) that “Although there was no significant visible corrosion on the broken rods (white corrosion or red rust) rust), some of the rods may have been exposed to water and the elements, especially at the bottom, . . .” For the other failed rods, all I am aware of are casual observations that the coating looked intact; I am not aware of any documented laboratory based examination results for these other failed rods.

Regards,

Jeff

Audrey Mantle
Dr. Gorman –

I read your draft response to the major issues raised in the Chung/Thomas reports and was left with the impression that I was reading the response from one side of a debating team.

To me, the main issue is whether the cause of the 32 anchor rod failures was hydrogen embrittlement (HE) caused by hydrogen introduced by the various manufacturing processes (including hot dip galvanizing) or if it was the result of external corrosion that occurred in the thread area of the anchor rods (which allowed hydrogen to be charged into the rods).
You seem to dismiss the “coincidence” of all 32 failures being at the bottom by suggesting that grouting the anchor rod sleeves prior to pre-tensioning to 0.70Fu may have allowed grout to lodge between the lower nut and washer or between the washer and its intended seating surface, thus creating an additive bending stress. I do not recall this being suggested in either the ABC failure analysis report or the subsequent report prepared under the direction of TBPOC. Additionally, if the construction sequence was as you suggest (grout first – preload second), was that the sequence intended by the designers and is there documentation that it occurred as you state? If so, it seems counterintuitive, since as you point out it could allow grout to get into areas it wasn’t intended to be. As such it would not be good construction practice. What possible reason would Caltrans have for doing the grout first?

The possibility that a greater amount of internal hydrogen was introduced during steel making because the 2008 steel heats were not vacuum degassed is plausible, but must remain in the realm of speculation for the following reasons. The manufacturer’s test report (Geedau Ameristeel Ht. #644912) indicates that the steel started as a continuous cast rod and was reduced 5.99 to 1; however, we do not know if the steel was sent to a soaking pit to diffuse the hydrogen at high temperature, and so far, there has been no attempt to measure the hydrogen content of failed 2008 rods, non-failed 2008 rods or non-failed 2010 rods.

As I recall the TBPOC report stated that water accumulated in the grout cans and Caltrans attempted to remove it several times during the approximately five year period between installation and pretensioning the anchor rods. This suggests there was at least an intermittent corrosive environment; and at worst, a continuous one in the crevices where the bottom nut engaged the bottom threads of the S1 and S2 anchor rods. In such an environment zinc plating will not perform as well as a normally dry environment with only intermittent wetting by San Francisco Bay air.

The phenomena of “white rust” is well known in the galvanizing industry and precautions are commonly recommended to separate zinc coated items to avoid rapid loss of the zinc coating if items are stored out-of-doors or in high humidity environments. It seems much more plausible that accelerated deterioration (corrosion) of the zinc charged hydrogen into the anchor rod bottom threads at the location where they mated with the bottom nuts. Unfortunately the ABC report did not show the condition of the zinc on the threads near the fracture face. Not a single photomicrograph of the thread root with zinc coating was presented in either the ABC failure report or the TBPOC or in any files released by TBPOC. This omission is just one of several that severely compromise the usefulness of the report in understanding the full metallurgical evidence and the most likely root cause. The report also failed to report surface hardness near the thread roots and (in my opinion) incorrectly use
Knoop hardness (load never reported) instead of using DPH (10 kg.) or simply Rockwell C hardness (150 kg.). Note: Knoop hardness measurements would have been the hardness test method for the thread root area.

A detailed comparison with the Hood Canal Floating Bridge bolt failure would be extremely helpful. If, as you state, both bolt batches of hot dip galvanized (HDG) 4140 anchor rods came from Dyson in 2008 and failed shortly after tensioning, the hardness, manufacturing history and storage conditions between manufacture and pre-tensioning would be valuable for understanding both the similarities and differences. (Is it possible to obtain a copy of these details and of the failure analysis report?)

Understanding the differences and similarities of the washers used in the two anchor rod systems would also be helpful. You state that the HCFB anchor rods used “thin” washers that somehow produced a bending stress at the bottom nut location. Are you aware that the nuts and washers used on the Bay Bridge anchor rods had hemispherical mating surfaces machined on them (apparently to avoid introducing localized bending stresses in case of misalignment)? This would appear to be a significant difference between the two cases.

Based on the preponderance of evidence currently available, I believe in would be prudent to concede that environmentally induced hydrogen embrittlement/SCC is the most likely root cause for the 2008 anchor rod failures, with a possible contribution from the presence of hydrogen from “less than state of the art” manufacturing practices or prevalent in most steel rods and HDG fasteners..

It’s my belief that Caltrans and TBPOC “rushed to judgment” in deciding that hydrogen embrittlement (as a result of hydrogen introduced during the manufacturing process) was the root cause. It was in their interest to do so because the 2008 anchor rods could be isolated from all the other rods and thus those failures could be quickly dealt with without initiating a broader inquiry and potentially further delaying the opening of a much delayed bridge. It was only later that they realized that it was prudent to consider that environmental exposure during the life of the bridge could lead to other failures of anchor rods at the high end of the hardness range permitted by ASTM A354 specification for Grade BD materials.

Ironically, they could have pointed out with even more plausibility that the embedded rods that anchored the shear keys were uniquely exposed to a highly corrosive environment for a period of years unlike the rest of the large 4140 anchor rods on the bridge.
In regard to the “M” shaped hardness traverse profiles reported for some of the (presumably) induction heat treated rods, your suggestion that the higher hardness at the ¼ radius location can be plausibly attributed to “inhomogeneity” in the 4140 alloy steel seems a bit far fetched. Certainly steel can be less than homogenous throughout its cross-section, but in my experience those areas tend to be located at the centerline of the material where segregation occurs at the last points of solidification. Centerline segregation to one degree or another is common in rolled plates that originate from cast slabs, including continuous cast strands. If, as reported, the anchor rod bars originated from continuous cast rounds, one would expect to see such inhomogeneity approximate at the centerline, not at the location where peak hardness has been reported. Can you perhaps point to a mechanism that would produce it elsewhere or to previous failure analysis documents that report such an unusual phenomenon? Again, it seems more plausible that the “anomaly” is the result of some unique aspect of the way the rods are being quenched and tempered. It is clearly not a surface decarburization issue. It would seem to be in Caltrans interests to get to the bottom of this, if for no other reason than to prevent future orders from having the same issues. It is my overall impression that Caltrans made no effort whatsoever to distinguish the technical requirements they specified for ASTM A354 Grade BD large diameter rods for the many thousands of ASTM A490 small diameter fasteners on the bridge. As long as the steel met the ASTM standard, they seemed unconcerned as to how the steel was melted, how it was reduced to final shape, specific methods for heat treatment (batch or inline induction), and only as the last minute did they attend to how it was to be cleaned prior to hot dip galvanizing.

By the way, I’m informed that even when galvanizers abrasively blast in lieu of an inhibited acid pickle, they perform a “flash acid cleaning” just prior to immersion in liquid zinc to remove particles imbedded from the blast media. If this was the case, how did Caltrans establish that this met their intent to avoid “acid pickling” and what limitations were placed on the flash acid cleaning?

Regards,

Harold Mantle

P.S. I did not copy others with the above comments, but I did share a rough draft of them with Mr. Chung.
The E2 pier cap, including the embedded 2008 shear key anchor rods, was completed by early 2009. Due to the extended construction schedule, Pier E2 was completed three years before the roadway boxes were erected in place over the pier. This resulted in the anchor rods being exposed to the environment for an extended period of time before the next construction stage, which would tension and grout them in place. This open environment is shown in a Pier E2 construction progress photograph (Figure 5) taken soon after completion of the pier cap. There were no provisions made in the design by the T.Y. Lin International/Moffatt & Nichol Design Joint Venture or the installation procedures prescribed by American Bridge/Fluor Joint Venture to include water drainage or sufficient rain protection to prevent the ingress and accumulation of rainwater or other moisture in the anchor rod housings during this extended period.

What Happened When the Rods Were Tensioned?

On March 1, 2013, following load transfer of the weight of the OBG roadway decks from the temporary falsework onto the main cable, American Bridge/Fluor Joint Venture tensioned the anchor rods at shear key S2. Between March 2 and March 5, 2013, American Bridge/Fluor Joint Venture tensioned the anchor rods at shear key S1. In accordance with contract plans and submittals, the rods were initially loaded to 0.75 Fu (i.e., 75 percent of their specified minimum ultimate tensile strength). Due to seating losses as the load is transferred from the hydraulic jack to the nut, the load then settled to its final design load of 0.68 Fu.

Between March 8, 2013 and March 14, 2013, 32 out of the 96 rods were discovered to have fractured. By March 14, 2013, Caltrans decided to lower the tension of the remaining unbroken rods from the 0.68 Fu to 0.45 Fu to avoid further fractures and to allow for investigation of the cause of the failures. The tension level was reduced on all unbroken rods. If the tension
What Were the Findings of the Metallurgical Analysis Conducted on the Failed Rods?

This section of the report provides a summary of the metallurgical analysis and testing performed on a sample of the failed 2008 rods.

A metallurgical investigative team, composed of a consultant to American Bridge/Fluor Joint Venture (Salim Brahim), a Caltrans metallurgist (Rosme Aguilar), and a consultant to Caltrans who is also principal-founder of Christensen Materials Engineering (Conrad Christensen), was tasked with examining the cause of the failures of the 2008 high-strength steel rods (Item #1 in Table 1). The full report of their findings is contained in Appendix H.13, but a summary is provided below and in Table 2.

The American Bridge/Fluor Joint Venture extracted nine of the 32 fractured rods. The metallurgical team concluded that a sample of nine rods was sufficient to yield reliable results about all the fractured rods based on ASTM F1470 sample sizes, and visual appearance of the fractured faces were found to be very similar. (Sample size required by ASTM F1470 is four rods.) Figure 7 illustrates the location of the 32 fractured rods and the nine extracted rods in shear keys S1 and S2, as listed below. The fractured rods were removed in multiple sections due to the small overhead clearance.

- 3/10/13: Shear Key S1 Location G1 (Sample #1)
- 3/11/13: Shear Key S2 Location A6 (Sample #2)
- 3/12/13: Shear Key S2 Location H6 (Sample #3)
- 3/13/13: Shear Key S1 Location A7 (Sample #4)
- 4/17/13: Shear Key S2 Locations A2, A3, A8 (Samples #7, 8, 9)
- 5/15/13: Shear Key S1 Locations H3, and H4 (Samples #5, 6)

Figure 7  Location of Fractured Rods in Shear Keys S1 and S2

![Diagram of Shear Keys S1 and S2 with locations of fractured rods]

No.: M-8312-01-12, Rev. 0 draft 02
To: 8312-01 Project File
From: Jeff Gorman, Dominion Engineering, Inc.
Date: February xx, 2014
Subject: Response to Comments of Harold Mantle Regarding Failures of Anchor Rods on the San Francisco Oakland Bay Bridge (SFOBB)

1 Objective

The objective of this memo is to provide responses to comments contained in an email from Mr. Harold Mantle dated January 27, 2014 [1], “Draft 10 of M-8312-01-10 Rev 0.” These comments were prepared by Mr. Mantle in response to an earlier DEI memo that discussed technical issues related to the SFOBB anchor rods [2].

2 Summary

Mr. Mantle’s email provides a useful review of several issues related to the anchor rods on the Self Anchored Suspension (SAS) bridge portion of the SFOBB, and warrants a detailed response. Towards this end, responses to each of his comments are contained in the Section 3, Discussion, of this memo. A summary of the main issues discussed by Mr. Mantle and of the responses to them follows:

- **Comment:** Mr. Mantle considers that the most likely cause of the failure of the 2008 rods was hydrogen ingress that occurred due to the rods being immersed in water during the five years they were installed in ducts but not tensioned or grouted during the 2008-2013 time period. He further indicates that, if this cause had been promptly recognized, this recognition could have significantly affected the actions taken in response to the failures.

- **Response:** It is recognized that exposure to water during the 5 years storage in the ducts is a possible factor in the ingress of hydrogen into the rods. However, there are several other plausible causes, as discussed in Section 3.1. In the period immediately after the failures of the 2008 rods it was judged imprudent not to investigate these other possible causes. In this regard, it was concluded that it is important to address all reasonably likely causes of failure in the corrective action program developed for the other rods. A factor in this conclusion was that the use of zinc coating on high strength rods makes them significantly susceptible to hydrogen embrittlement and stress corrosion cracking (HE/SCC). The need to address all plausible causes of HE/SCC makes the issue of determining the exact cause
of the failure of the 2008 rods not very important since the corrective measures will address all the plausible causes, including whichever cause applied to the failure of the 2008 rods.

- **Comment:** The causes of the M shaped hardness traverse profile exhibited by some of the rods should be determined. The implication is that these causes should be determined to ensure that they do indicate a problem with the ability of the rods to meet their design functions.

- **Response:** Possible causes of the M shaped hardness traverse have been discussed with several steel suppliers. Based on these discussions, it is concluded that variations in heat input during tempering by either induction or oven processes could lead to M shaped hardness profiles. The presence of such profiles was not identified as indicating a problem with the ability of the rods to meet their design functions.

Metallurgical examinations of similar rods have shown hardness variations across the diameter associated with banding of tempered martensite and non-martensite transformation products. While the banding leads to significant hardness variations, it is not considered likely to be a cause of the systematic development of M shaped hardness profiles such as observed with some sets of anchor rods on the SFOBB.

The information gathered to date leads to a conclusion that the M shaped hardness profiles are not indicative of a problem that affects the ability of the rods to meet design requirements. However, in order to better understand the causes of the hardness profile, the post mortem examinations of the rods from Test IV will include metallurgical examinations across the cross section to determine what factors are associated with changes in the measured hardness values.

3 **Discussion**

Mr. Mantle’s comments are presented and discussed below in a comment by comment manner, starting with the comments of paragraph 2 (paragraph 1 is non-technical in nature).

3.1 **Source of Hydrogen**

**Comment:** “To me, the main issue is whether the cause of the 32 anchor rod failures was hydrogen embrittlement (HE) caused by hydrogen introduced by the various manufacturing processes (including hot dip galvanizing) or if it was the result of external corrosion that occurred in the thread area of the anchor rods (which allowed hydrogen to be charged into the rods).”

**Response:** It is agreed that firmly determining the root cause of the failure as discussed in the above comment would be helpful. Unfortunately, making a firm determination is difficult, for the following reasons:

- Based on the metallurgical failure analysis of the failed rods (Reference [3]), it is clear that the failures were due to hydrogen in the steel. However, as indicated in the failure analysis report, the source of the hydrogen could have been from external corrosion or from
hydrogen trapped in the steel. In this regard, the failure analysis report cites research performed by S. Brahim [4] that discusses how hydrogen trapped in the steel can be released by the hot dip galvanizing process and cause subsequent hydrogen embrittlement failures. This mechanism is also discussed in Townsend’s 1975 paper that deals with the effects of galvanizing on HE/SCC [5], which notes that “hydrogen is released from traps during hot-dipping and prevented from escaping by the intermetallic layers”.

- It seems somewhat unlikely that hydrogen could have entered all of the lower ends of the rods during five years of service. This is because the rods, including the threaded ends, had been hot dipped galvanized and the rods had been protected by Denso tape. Since zinc corrosion rates in severe marine environments are indicated as being about 0.15 mils (3.8 μm) [6], it seems unlikely that the zinc coating, which is believed to have been about 2 or more mils thick initially, would have been penetrated on all of the rods. In addition, visual examinations of the threaded ends of the failed rods above the fracture surface do not show signs of obvious corrosion. It is planned to perform more detailed examinations of these ends to more fully characterize the condition of the zinc coating at the threaded ends.

- Another failure mechanism that has been proposed is that hydrogen entered the rods at breaks in the zinc coating caused by the tensioning. This seems somewhat unlikely since the area below the rods and between the rods and the sleeves had been filled with grout, such that all water should have been displaced prior to tensioning (see Figure 1).

- Failures at the bottom end could possibly have been caused by something that applied a bending moment there. This type of bending has been identified as a factor involved in the Hood Canal Floating Bridge rod failures, as discussed in Reference [2]. (It would be useful to provide Mr. Mantle a copy of the HCFB report.) As discussed in a previous memo [2], this might have been due to grout getting into the nut to washer interface. A more likely scenario is foreign material in the washer to end plate interface (see Figure 1 for details of the geometry and for a definition of the grouting and tensioning sequence). The rods were in a lowered position in their top hats for five years (see Figure 1), such that foreign material could have fallen down the ducts and through the grout holes in the end plates, and then accumulated on the tops of the washers and caused bending when the rods were raised into position and tensioned.

Tests of material from the 2008 failed rods are planned and may show the presence of internal hydrogen. These tests are part of the Test V series of tests and include rising step load bend tests in air of specimens with fatigue sharpened pre-cracks following the protocol of ASTM-F1629 (incremental load step tests). The rod material, which was removed from the pier by cutting the rods into short lengths, has been stored since April 2013 at room temperature in air, such that internal hydrogen could have diffused out. If the tests show evidence of HE, this will be conclusive that internal hydrogen from steel making was involved in the failures. However, if the tests do not show effects of internal hydrogen, one cannot conclude that hydrogen was not present at the time they were tensioned since the hydrogen could have diffused out since that time.
As discussed above, there remains uncertainty regarding the source of the hydrogen that caused the failures of the 2008 rods. While resolving this uncertainty would be useful, it seems unlikely that a positive answer will be developed with high assurance. Considering this uncertainty, it is judged to be important that the remedial measures taken at the bridge address both internal and external sources of hydrogen.

3.2 Grouting Sequence

Comment: “You seem to dismiss the “coincidence” of all 32 failures being at the bottom by suggesting that grouting the anchor rod sleeves prior to pre-tensioning to 0.70Fu may have allowed grout to lodge between the lower nut and washer or between the washer and its intended seating surface, thus creating an additive bending stress. I do not recall this being suggested in either the ABC failure analysis report or the subsequent report prepared under the direction of TBPOC. Additionally, if the construction sequence was as you suggest (grout first – preload second), was that the sequence intended by the designers and is there documentation that it occurred as you state? If so, it seems counterintuitive, since as you point it could allow grout to get into areas it wasn’t intended to be. As such it would not be good construction practice. What possible reason would Caltrans have for doing the grout first?”

Response: The grouting sequence used by the constructor (ABF) is described in Figure 1, and indicates that grout was installed before tensioning. The sequence of grouting desired by the designer (the DJV) is shown in Note 9 on Figure 2. The wording of this note indicates that the grout must be in place to allow proper tensioning of the rods, i.e., that grouting must occur before tensioning. The method that was specified to be used to prevent grout from getting into the nut-washer interface is indicated on Figure 1, and involved tightening the top nut to a “snug” fit. Unless this step was not correctly performed for some systematic reason, it seems unlikely that grout could have gotten into a large number of nut-washer interfaces or washer-end plate interfaces. However, as noted in the previous section, it seems possible that foreign material fell down the duct and through the grout holes in the end plate (see Figure 1) and collected on top of the washer, and subsequently caused uneven seating of the washer on the end plate when the rod was lifted and tensioned.

3.3 Internal Hydrogen and Vacuum Degassing

Comment: “The possibility that a greater amount of internal hydrogen was introduced during steel making because the 2008 steel heats were not vacuum degassed is plausible, but must remain in the realm of speculation for the following reasons. The manufacturer’s test report
(Geedau Ameristeel Ht. #644912) indicates that the steel started as a continuous cast rod and was reduced 5.99 to 1; however, we do not know if the steel was sent to a soaking pit to diffuse the hydrogen at high temperature, and so far, there has been no attempt to measure the hydrogen content of failed 2008 rods, non-failed 2008 rods or non-failed 2010 rods.”

Response: The fact that the material certification records for the 2010 rods specifically state that the steel was vacuum degassed, while they do not for the 2008 rods, indicates that there probably was a difference in the quality of the steels. The implications of requiring magnetic particle inspection of the rods, which was required for the 2010 rods but not the 2008 rods, were discussed with several material suppliers (Gerdau, Vulcan and Timken). They indicate that when it is known that magnetic particle inspections of rods must be passed for acceptance, a higher quality steel making process is selected including vacuum degassing. This reduces the levels of internal hydrogen and also results in cleaner steel with a lower likelihood of rejectable indications on the surface.

With regard to testing for effects of internal hydrogen, Test V includes rising step load tests in an air environment of the 2008 rod material. These tests should show if sufficient hydrogen is still in the steel to cause HE failures. However, since the cut sections of the rods have been exposed to the air for a long time, lack of HE would not be conclusive evidence that internal hydrogen was not a factor since the hydrogen could have diffused out.

3.4 Exposure to Aggressive Environment

Comment: “As I recall the TBPOC report stated that water accumulated in the grout cans and Caltrans attempted to remove it several times during the approximately five year period between installation and pretensioning the anchor rods. This suggests there was at least an intermittent corrosive environment; and at worst, a continuous one in the crevices where the bottom nut engaged the bottom threads of the S1 and S2 anchor rods. In such an environment zinc plating will not perform as well as a normally dry environment with only intermittent wetting by San Francisco Bay air.”

Response: It is agreed that the evidence suggests that there was water in the ducts, at least intermittently. The number of ducts that had water in them, and for how long, is not known. The aggressiveness of the environment in the wetted ducts would depend on the concentration of impurities in the water. If it was mainly rain water, the concentration of impurities may have been low. However, it is possible that there was a significant salt concentration from marine atmosphere aerosols. With regard to how the aggressiveness would compare to that formed by intermittent wetting by San Francisco Bay air, the answer is again uncertain. In SCC tests of
uncoated steel, intermittent wetting by salt water is more aggressive than immersion in a salt water bath (page 53 of [7]).

Our net conclusion based on the above information is that seems possible but unlikely that the zinc coating at the lower ends of many of the 2008 rods developed penetrations that resulted in ingress of hydrogen to damaging levels. This is mainly based on the known good performance of zinc coatings with typical lifetimes of 20 years or more, and the absence of visible signs of corrosion on the lower threaded portions of the failed rods. The possibility of performing more detailed examination of these threaded ends is being pursued, and may help to resolve this question.

3.5 Condition of Zinc Near Failure; Hardness Test Methods

Comment: “The phenomena of “white rust” is well known in the galvanizing industry and precautions are commonly recommended to separate zinc coated items to avoid rapid loss of the zinc coating if items are stored out-of-doors or in high humidity environments. It seems much more plausible that accelerated deterioration (corrosion) of the zinc charged hydrogen into the anchor rod bottom threads at the location where they mated with the bottom nuts. Unfortunately the ABC report did not show the condition of the zinc on the threads near the fracture face. Not a single photomicrograph of the thread root with zinc coating was presented in either the ABC failure report or the TBPOC or in any files released by TBPOC. This omission is just one of several that severely compromise the usefulness of the report in understanding the full metallurgical evidence and the most likely root cause. The report also failed to report surface hardness near the thread roots and (in my opinion) incorrectly use Knoop hardness (load never reported) instead of using DPH (10 kg.) or simply Rockwell C hardness (150 kg.). Note: Knoop hardness measurements would have been the hardness test method for the thread root area.”

Response: It is agreed that more detailed examinations of the condition of the zinc in the threaded area adjacent to the fracture would be useful and may provide insights as to whether enough degradation of the zinc had occurred to allow external HE to proceed. Performance of this type of examination is being pursued.

With regard to the hardness tests performed for the failure analysis (Reference [3]), Rockwell C tests of the type suggested in the comment were performed by two different laboratories and indicated hardness values and profiles similar to those measured for many other rods on the bridge. The comment suggests that the Knoop hardness test method was inappropriate. (Can I talk to the metallurgist who did the hardness testing?) It is agreed that Knoop hardness methods are commonly used for thin brittle pieces, and thus would be a possible choice for hardness
measurements in the thread root area. Measurements of the hardness of thread root areas are
being pursued in connection with the Test V test program.

3.6 Hood Canal Floating Bridge Report

Comment: “A detailed comparison with the Hood Canal Floating Bridge bolt failure would be
extremely helpful. If, as you state, both bolt batches of hot dip galvanized (HDG) 4140 anchor
rods came from Dyson in 2008 and failed shortly after tensioning, the hardness, manufacturing
history and storage conditions between manufacture and pre-tensioning would be valuable for
understanding both the similarities and differences. (Is it possible to obtain a copy of these
details and of the failure analysis report?)”

Response: Can we provide Mantle with a copy of the Hood Canal Floating Bridge report?

3.7 Washers

Comment: “Understanding the differences and similarities of the washers used in the two anchor
rod systems would also be helpful. You state that the HCFB anchor rods used “thin” washers
that somehow produced a bending stress at the bottom nut location. Are you aware that the nuts
and washers used on the Bay Bridge anchor rods had hemispherical mating surfaces machined on
them (apparently to avoid introducing localized bending stresses in case of misalignment)? This
would appear to be a significant difference between the two cases.”

Response: The washers used with the Hood Canal Floating Bridge anchor rods are described in
Reference __. Can we provide Mantle with a copy of the Hood Canal Floating Bridge report?

It is agreed that the hemispherical nuts and washers on the Bay Bridge anchor rods are designed
to minimize the development of bending stresses. However, if grout inadvertently was
introduced into the nut to washer or washer to end plate interfaces, or if foreign material
collected on top of the washers, bending stresses could have developed when the rods were
raised and tightened. Assessing the probability of these conditions having affected large
numbers of anchor rods is difficult, but they nevertheless remain possibilities that should be
considered.

3.8 Paragraph 2 - Most Likely Root Cause

Comment: “Based on the preponderance of evidence currently available, I believe in would be
prudent to concede that environmentally induced hydrogen embrittlement/SCC is the most likely
root cause for the 2008 anchor rod failures, with a possible contribution from the presence of
hydrogen from “less than state of the art” manufacturing practices or prevalent in most steel rods and HDG fasteners.”

Response: It is agreed that environmentally induced HE/SCC is a strong candidate for being the main cause of the failures of the 2008 rods. It is further concluded that taking steps to make sure that occurrence of such environmentally induced HE/SCC will not occur in the other anchor rods on the SAS is important. This is the main focus of the TPNOC program now that the likelihood of HE due to hydrogen from internal sources in the steel has been found to be insignificant (based on no cracking detected after more than nine months of service in a tensioned condition).

3.9 Rush to Judgment

Comment: “It’s my belief that Caltrans and TBPOC “rushed to judgment” in deciding that hydrogen embrittlement (as a result of hydrogen introduced during the manufacturing process) was the root cause. It was in their interest to do so because the 2008 anchor rods could be isolated from all the other rods and thus those failures could be quickly dealt with without initiating a broader inquiry and potentially further delaying the opening of a much delayed bridge. It was only later that they realized that it was prudent to consider that environmental exposure during the life of the bridge could lead to other failures of anchor rods at the high end of the hardness range permitted by ASTM A354 specification for Grade BD materials.”

Response: The April 24, 2013 presentation by BATA noted that “Sources of excess hydrogen may have been both internal (residual from production) and/or external.” This indicates that shortly after the failures were discovered and analyzed it was recognized that hydrogen introduced by corrosion was a possible cause of the failures. This is also indicated in the TPNOC report (e.g., page ES-10 of Reference [8]), which notes that emersion in water during the five year period that the rods were installed on the bridge “may have been a contributing source of hydrogen contamination in the rods.” It was largely in response to this understanding that an extensive evaluation of the possibility of HE/SCC affecting the other anchor rods was initiated, and development of protective methods initiated or expanded (such as dehumidification and installation of grease caps). These aspects are discussed in Sections 6 and 8 of the TPNOC report [8].

3.10 Paragraph 2 - Unique Causes of Failure of 2008 Rods

Comment: “Ironically, they could have pointed out with even more plausibility that the embedded rods that anchored the shear keys were uniquely exposed to a highly corrosive environment for a period of years unlike the rest of the large 4140 anchor rods on the bridge.”
Response: As discussed in response to earlier comments, the importance of corrosion during the five years that the 2008 rods were installed on the bridge to the rapid occurrence of HE failures is not as clear cut as presented in the above comment. Because of the uncertainty involved in determining the full causes of the failure it was, and remains, important to address all of the possible causes of the failures, including both internal and external sources of hydrogen. In this regard, it would have been imprudent to have concluded that only the 2008 rods were susceptible to external hydrogen embrittlement. While the corrosive conditions for the 2008 rods may have been more severe that for the other rods, that does not mean that the other rods are not susceptible to longer term HE/SCC. Because the other rods have similar hardness levels and zinc coatings they have similar susceptibility to HE/SCC if corrosive conditions should develop. It is for these reasons that ensuring that appropriate corrosion protective measures are applied is an important part of the corrective action program.

3.11 M Shaped Hardness Traverse Profile

Comment: “In regard to the “M” shaped hardness traverse profiles reported for some of the (presumably) induction heat treated rods, your suggestion that the higher hardness at the ¼ radius location can be plausibly attributed to “inhomogeneity” in the 4140 alloy steel seems a bit far fetched. Certainly steel can be less than homogenous throughout its cross-section, but in my experience those areas tend to be located at the centerline of the material where segregation occurs at the last points of solidification. Centerline segregation to one degree or another is common in rolled plates that originate from cast slabs, including continuous cast strands. If, as reported, the anchor rod bars originated from continuous cast rounds, one would expect to see such inhomogeneity approximate at the centerline, not at the location where peak hardness has been reported. Can you perhaps point to a mechanism that would produce it elsewhere or to previous failure analysis documents that report such an unusual phenomenon? Again, it seems more plausible that the “anomaly” is the result of some unique aspect of the way the rods are being quenched and tempered. It is clearly not a surface decarburization issue. It would seem to be in Caltrans interests to get to the bottom of this, if for no other reason than to prevent future orders from having the same issues. It is my overall impression that Caltrans made no effort whatsoever to distinguish the technical requirements they specified for ASTM A354 Grade BD large diameter rods for the many thousands of ASTM A490 small diameter fasteners on the bridge. As long as the steel met the ASTM standard, they seemed unconcerned as to how the steel was melted, how it was reduced to final shape, specific methods for heat treatment (batch or inline induction), and only as the last minute did they attend to how it was to be cleaned prior to hot dip galvanizing.”
Response: It is agreed that the most likely source of the M shaped hardness profile is a result of the quench and temper process. It is noted that the M shaped hardness profile is exhibited by rods that were heat treated by induction methods (e.g., the ID#12 and #13 Tower Anchor Rods) and by oven methods (e.g., the ID#8 Tower Saddle Tie Rods). We have discussed the occurrence of the M shaped hardness profiles with several steel manufacturers. They all indicate that, as long as the rods meet the mechanical property requirements of ASTM A354, e.g., tensile strength and hardness limits, the M shaped profiles are not indicative of problems. They further indicate that such types of profiles can be developed by variations in the tempering process such as durations and locations of heat input during induction tempering, and changes in oven temperature during oven tempering. It is noted by DEI that having a lower hardness in the outer layer of the rods, e.g., in the outer ½ inch, is beneficial since it reduces susceptibility to initiation of SCC.

Another possible factor causing changes in hardness profiles is material banding of the type discussed in a recent examination of similar rods from the Hood Canal Floating Bridge (HCFB). That examination was of 3 inch diameter rods made by Dyson in 2008 that failed shortly after tensioning. The examination indicated that the microstructure varied across the cross section, with some bands being tempered martensite with relatively high hardness and other bands being non-martensite transformation products with lower hardness [10]. It was indicated that this type of variability is typical for large diameter bars made of 4140 steel. While this is a possible factor for individual rods, it does not seem likely to lead to systematic repeatable M shaped hardness profile.

Checks of the microstructure and how it correlates with the hardness across the cross sections of rods have been added to the protocol for post mortem examination of rods tested in Test IV. It is expected that these results will provide an improved understanding of the causes of the M shaped hardness profiles.

3.12 Paragraph 2 - Flash Acid Cleaning

Comment: “By the way, I’m informed that even when galvanizers abrasively blast in lieu of an inhibited acid pickle, they perform a “flash acid cleaning” just prior to immersion in liquid zinc to remove particles imbedded from the blast media. If this was the case, how did Caltrans establish that this met their intent to avoid “acid pickling” and what limitations were placed on the flash acid cleaning?”

Response: The QC records for the 2008 and the 2010 Pier E2 rods indicate that the rods were blasted, then immersed in a pre-flux bath, and then immersed in the hot dip galvanizing bath.
There is no mention of there being an acid pickling step. It appears that flash pickling was not required nor performed for these sets of rods. Thus, control of the flash pickling process was not an issue for these sets of rods. Perhaps a more important consideration for the 2010 rods is that they have been tensioned for more than ten months with no failures. This indicates that hydrogen embrittlement caused by hydrogen from the rod manufacturing process is not a concern, since failures from manufacturing sources of hydrogen usually occur within a few weeks of tensioning.

4 References


2. DEI Memo 8312-01-10, Rev 0, January 20, 2014, “Review of Technical Issues Raised in October and November 2013 reports by Chung and Thomas re Anchor Rods on the San Francisco Oakland Bay Bridge (SFOBB).”


Figure 1. Bottom End of Anchor Rod and Installation Sequence
Figure 2. Grouting Instructions.
February 10, 2014

Brian A Petersen  
Project Executive  
American Bridge/Fluor, A JV  
375 Burma Road  
Oakland, CA 94607

Dear Brian Petersen,

**Supplemental Notice of Potential Claim No. 19**

The Department has reviewed ABF-CAL-LTR-001980, “Potential Claim Number 19 Tower Electroslag Welding Submission of Supplemental Notice of Potential Claim,” dated January 24, 2014; regarding repairs associated with transverse indications in the tower electroslag welds (ESW).

While not clearly stated in the NOPC, it is the Department’s understanding that ABFJV believes that the Transverse Indications (TIs) do not require repair per AWS D1.5 Table 6.4 UT Acceptance - Rejection Criteria - Compressive Stress. However, as the transverse indications remained on the display as the search unit was moved (aka. walking indications), Table 6.4 bullet 5 and the approved WQCP Section 6.6.21 requires further investigation in accordance with AWS Clause 6.26.3.2.

ABFJV in collaboration with the Department, further evaluated these indications. It was ABFJV’s decision to perform their evaluation by excavation. Once excavated these indications were identified to be cracks. This was further illustrated by Dr. John Barsom’s evaluation of the PQR and mockup plates. These plates contained TI’s representative of that found in the production work. Through this evaluation, Dr. Barsom identified the indications as intergranular boundary separations and fissures. Intergranular boundary separations and fissures are further defined by AWS as cracks. In accordance with Clause 6.26 Quality of Welds, there shall be no cracks.

Because the TI’s are cracks, the electroslag welds containing TIs do not comply with the contract documents. Given this information, the Department requests that ABFJV withdraw NOPC 19.

However, if ABFJV desires to continue forward with the NOPC, please provide a detailed explanation of ABFJV’s position so that the Department may further evaluate this issue. As part of the explanation, the following information is requested.
1. What are the ABFJV Quality Control Manager’s interpretations of excavation reports ER001 through ER006 in accordance with AWS D1.5?

2. The following statement is made in ABF-LET-1980: “In certain ESWs, NDT revealed transverse type (by orientation) discontinuities, or Transverse Indications (TI’s). Because of these TI’s, the Department has not accepted these welds” (emphasis added). Using the naming convention for the ESW welds, please identify exactly which welds are being referenced.

3. Please provide the ABFJV QC acceptance document signed by the QCM stating the welds were acceptable prior to the TI repairs.

4. Why did ABFJV repair all TIs in the Ring Beam zone beginning May 2013?

5. In accordance with the contract requirements, provide a description of how the NOPC 19 cost estimate was derived, how ABF is separating claimed costs from item work, and an itemized breakdown of all costs; including all labor, equipment and materials.

6. ABF has also requested compensation for successor activities. Please provide a detail list of these activities and include the cost estimates in Item 5 above.

As stated above, if ABFJV wishes to further pursue NOPC 19. Please provide the explanation and additional information within 15 days. If ABFJV has any questions/concerns regarding this letter, the Department is willing to meet to further discuss this issue anytime.

Sincerely,

WILLIAM S. CASEY
Resident Engineer

cc:
file: 05.03.01, 62.02.019

"Caltrans improves mobility across California"