QC/QA Process & A354 BD Rod Testing Program

Bahjat Dagher, PE
Material Engineering & Testing Services
Outline

- Section I: Introduction
- Section II: Fabrication Process
- Section III: Quality Assurance
- Section IV: Testing Program for SAS Rods
Section I: Introduction

- 2,306 anchor rods
- 17 groups of rods
A354 Gr BD Anchor Rods SAS
A354 Gr BD Anchor Rods SAS
A354 Gr BD Anchor Rods SAS
Section II – Fabrication Process
Fabrication Process

- Shipment of material from the mill to the fabricator
Fabrication Process

- Quenched & tempered
  - Oven heated
  - Induction coil
- Hardness, strength, grain size, other properties
Fabrication Process

- All rod threads were cut with the exception of:
  - E2 Bearing Top Rods (B1, B2, B3, B4) – Rolled
  - PWS Anchor Rods (80%) – Rolled
  - Tower Saddle Tie Rods – Rolled
  - B14 Cable Band Anchor Rods – Rolled
Fabrication Process

• Mechanical Properties per ASTM A354
• MT performed on rods specified by CCO 91
Fabrication Process

- Dry blast cleaned to a near white finish (SP-10) prior to galvanizing per ASTM A123
Section III – Quality Assurance
Quality Assurance

- Facility audits in 2007 and 2008
- Audit performed by Caltrans
- Final results of audits: Pass
Quality Assurance

- In-process inspection
- Thread dimensional verification
- Magnetic Particle Testing
Quality Assurance

- Document verification
  - Certificate of Compliances
  - Mill Test Reports
  - QC test results
Quality Assurance

- Defined in state letter dated July 14, 2008
- One full size sample per heat
- Two reduced size samples per heat
Quality Assurance

- Tests performed:
  - Full size tension
  - Reduced section tension
  - Hardness
  - Coating thickness
Quality Assurance

Orange Tag
- Material conforms to contract requirements

Blue Tag
- Material does not conform to contract requirements but accepted as fit for purpose
QC/QA Documentation
Section IV – Testing Program for SAS Rods
Testing Program

- Contract Specified QC/QA
- Tensioning & Monitoring of Remaining Rods
- Test I – Field Hardness Test (in-situ)
- Test II – Laboratory Test
- Test III – Full Size Test
- Test IV – Stress Corrosion Test (Dr. Townsend)
- Test V – Incremental Step Loading Test (Dr. Raymond)
- Test VI – Slow Rate & Sustained Loading Test (Dr. Gorman)
Tensioning & Monitoring of Remaining Rods

- 2010 anchor rods tensioned in April 2013
- 10 Rods were monitored using Acoustic Emissions
- No cracks were detected
Test I: Field Hardness Test (*in-situ*)

- UCI Test Method
- 1,361 Rods tested on bridge
## Test I: Field Hardness

<table>
<thead>
<tr>
<th>Rods</th>
</tr>
</thead>
<tbody>
<tr>
<td>287</td>
</tr>
<tr>
<td>224</td>
</tr>
<tr>
<td>96</td>
</tr>
<tr>
<td>138</td>
</tr>
<tr>
<td>270</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>36</td>
</tr>
<tr>
<td>226</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>
Test I: Field Hardness Test (*in-situ*)

- Performed in-situ
- Cleaned from oil, grease, and rust
- Top surface galvanizing removed by grinding
Test I: Field Hardness Test (*in-situ*)

- Top surface sanded to achieve profile 15 µm or less
- Roughness verified with a profile meter
Test I: Field Hardness Test (*in-situ*)

- Multiple points on each rod
- Multiple readings at each point
- Verified against a calibrated block
Test I: Field Hardness Test (*in-situ*)

4” Rod
Test II: Laboratory Testing

- Hardness Test
- Spectrochemical Analysis
- Charpy Impact Test (if available)
Test II: Laboratory Testing

- 12 Rods
- 7 Rods
- 43 Rods
- 2 Rods
- 6 Rods
- 3 Rods
- 2 Rods
- 2 Rods
- 1 Rod
Test II: Laboratory Testing - Samples

Sample

76 mm

19 mm

185 mm
Test II – Rockwell C Hardness

- 12.5 mm thick sample
- Test at 3 mm increments and one location at R/2 in each quadrant
Test II – Rockwell C Hardness

- Average hardness values for PWS Anchor Rods and Tower Saddle Tie Rods
“M” Shape Curve Investigation

- Tilting of sample during testing of the edges
- Testing of longitudinal samples
- Similar results observed
“M” Shape Curve Investigation

- Decarburization
  - ASTM F2328 tests performed
  - No evidence of decarburization

- Microstructural Examination
  - At the HRC indentations
  - In progress
Test II – Chemical Analysis

- Spectrochemical analysis
- Min. 3 samples per rod: Center, perimeter, R/2
- All tested rods met A354 BD chemical requirements
Test II – Charpy Impact Test

- 10 x 10 specimens
- 3” to 4” Rods – 6 specimens along circumference
- 2” Rods – 3 specimens along circumference
  6 specimens total
Test II – Charpy Impact Test

Data points are averages of several tests from multiple samples

<table>
<thead>
<tr>
<th>Item</th>
<th>40F</th>
<th>70F</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3</td>
<td>36.9</td>
<td>37.6</td>
</tr>
<tr>
<td>#4</td>
<td>27.3</td>
<td>36.7</td>
</tr>
<tr>
<td>#7</td>
<td>39.0</td>
<td>40.8</td>
</tr>
<tr>
<td>#8</td>
<td>16.9</td>
<td>20.8</td>
</tr>
<tr>
<td>#9 Heat 1</td>
<td>52.3</td>
<td>52.7</td>
</tr>
<tr>
<td>#9 heat 2</td>
<td>13.0</td>
<td>16.0</td>
</tr>
<tr>
<td>#12</td>
<td>39.1</td>
<td>41.8</td>
</tr>
<tr>
<td>#13</td>
<td>31.7</td>
<td>36.3</td>
</tr>
<tr>
<td>#15</td>
<td>17.8</td>
<td>23.7</td>
</tr>
</tbody>
</table>

Note: The data points are expressed in foot-pounds (ft-lbs) and are averages of several tests from multiple samples.
Test III: Full-Size Tension Testing

- Full-Size Tension Test
- Reduced-Size Tension Test
- Rockwell C Hardness
- Knoop Micro-Hardness
- Charpy Impact Test
- Metallurgical Analysis
- Microstructural Analysis
- Galvanization Chemistry
Test III: Full Size Testing
Test III – Full Size Tension Test

- Loaded to failure at a constant rate.
Test III – Full Size Tension Test

- Full size samples selected from 8 groups for tension
Test III: Full-Size Testing

- Specimens are extracted from a full size rod.
Test III – Reduced Size Tension Test

- Reduced size tension tests / .505
Test III – Reduced Size Tension Test

Tensile Stress ksi

Group 2
Group 3
Group 4
Group 7
Group 8
Group 12
Test III – Metallurgical Analysis

- Metallurgical and Fracture Analysis
- Scanning electron microscope (SEM)
Test III – Metallurgical Analysis

Region 1

- Fracture Initiation areas indicate ductile tearing as a result of tensile overload.
Test III – Metallurgical Analysis

Region 2

- Propagation area shows fracture features of both cleavage & ductility.
Test III – Metallurgical Analysis

Region 3

- Final Fracture areas show dimpled ductile features.
Test III – Microstructural Analysis

- Inclusions and banding in steel
QUESTIONS