Items Expected at July 10 BATA Briefing

- Completion of written TBPOC investigative report, plus
- Firm schedule for E2 2008 bolt retrofit, plus
- Decision on other bolts on SAS, equals
- Decision on Seismic Safety Opening Date of Bay Bridge.
Causes of Hydrogen Embrittlement (HE) or Stress Corrosion Cracking (SCC)

- Presence of Hydrogen
- High Tensile Stress
- Material Susceptibility
- HE/SCC
A354 Grade BD Rod Locations on the SAS Bridge

- **Top of Tower**
  - 8-9
  - 10-11

- **Top of Pier W2**
  - 17

- **Bottom of Tower**
  - 12-13

- **Anchorage**
  - East Cables
  - East Saddles
  - 16, 14-15, 7
  - Top of Pier E2
  - 1-6

- Rod Locations
- Rod Locations (Dehumidified)
## A354 Grade BD Rods on the SAS Bridge

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Location</th>
<th>Component</th>
<th>Quantity Installed</th>
<th>Diameter (in)</th>
<th>Length (ft)</th>
<th>Tension (fraction of $\text{Fu}^*$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top of Pier E2</td>
<td>Shear Key Anchor Rods (2008)</td>
<td>96</td>
<td>3</td>
<td>10-17</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Bearing &amp; Shear Key Anchor Rods</td>
<td>192</td>
<td>3</td>
<td>22-23</td>
<td>0.7</td>
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<tr>
<td>3</td>
<td></td>
<td>Shear Key Rods (top)</td>
<td>320</td>
<td>3</td>
<td>2-4.5</td>
<td>0.7</td>
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<tr>
<td>4</td>
<td></td>
<td>Bearing Rods (top)</td>
<td>224</td>
<td>2</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Bearing Assembly</td>
<td>96</td>
<td>1</td>
<td>2.5</td>
<td>0.6</td>
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<tr>
<td>6</td>
<td></td>
<td>Bearing Retainer Ring Plate Assembly</td>
<td>336</td>
<td>1</td>
<td>0.2</td>
<td>0.4</td>
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<td>7</td>
<td>Anchorage</td>
<td>Parallel Wire Strands (PWS) Anchor Rods</td>
<td>274</td>
<td>3.5</td>
<td>28-32</td>
<td>0.3</td>
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<tr>
<td>8</td>
<td>Top of Tower</td>
<td>Saddle Tie Rods</td>
<td>25</td>
<td>4</td>
<td>6-18</td>
<td>0.7</td>
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<tr>
<td>9</td>
<td></td>
<td>Saddle Turned Rods</td>
<td>108</td>
<td>3</td>
<td>1.5-2</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Saddle Grillage</td>
<td>90</td>
<td>3</td>
<td>1</td>
<td>0.1</td>
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<tr>
<td>11</td>
<td></td>
<td>Outrigger Boom</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0.1</td>
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<tr>
<td>12</td>
<td>Bottom of Tower</td>
<td>Tower Anchor Rods (Type 1)</td>
<td>388</td>
<td>3</td>
<td>26</td>
<td>0.5</td>
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<td>13</td>
<td></td>
<td>Tower Anchor Rods (Type 2)</td>
<td>36</td>
<td>4</td>
<td>26</td>
<td>0.4</td>
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<td>14</td>
<td>East Saddles</td>
<td>East Saddle Anchor Rods</td>
<td>32</td>
<td>2</td>
<td>3</td>
<td>0.1</td>
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<tr>
<td>15</td>
<td></td>
<td>East Saddle Tie Rods</td>
<td>18</td>
<td>3</td>
<td>5</td>
<td>0.1</td>
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<tr>
<td>16</td>
<td>East Cable</td>
<td>Cable Band Anchor Rod</td>
<td>24</td>
<td>3</td>
<td>10-11</td>
<td>0.2</td>
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<td>17</td>
<td>Top of Pier W2</td>
<td>Bikepath Anchor Rods</td>
<td>43</td>
<td>1.2</td>
<td>1.5</td>
<td>TBD</td>
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<tr>
<td></td>
<td>TOTAL QUANTITY</td>
<td></td>
<td></td>
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<td>2,306</td>
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Looking Back
Bearings and Shear Keys on Pier E2
2008 Rods Failed Due to Hydrogen Embrittlement

- Rods exhibited a material susceptibility to hydrogen embrittlement with a heterogenous structure and high surface hardness.
TBPOC Investigation of High Strength Steel Rods

- Conducted four half-day workshops and held 25+ other meetings or conference calls
- Reviewed over 5,000 pages of material
- Consulted with industry experts, Seismic Peer Review Panel, and FHWA team
- Briefed BATA and Bay Area State Legislators on multiple occasions
SAS Responsible Parties

- Caltrans is the Owner/Operator.

- TY Lin International/Moffatt & Nichol Design Joint Venture is the Engineer of Record.

- American Bridge/Fluor Joint Venture is the Contractor for the SAS Superstructure.
Findings – Owner, Designer, Contractor

- Per the joint metallurgical report, 2008 rods had “…higher than normal susceptibility of the steel to hydrogen embrittlement,” but complied with specifications selected by the designer and owner of project.

- Embedded rod design did not adequately address drainage, while contractor did not adequately provide on-site protection of 2008 rods from the environment during construction.
Findings – Owner & Designer

- Failed to consider different uses and tension levels for high-strength rods on SAS
- Did not adequately evaluate alternative rod materials and procurement methods (i.e., sole sourcing)
- Did not account for combined effect of rod type selection and corrosion protection methods
Findings – Owner & Designer (con’t)

- Failed to adequately consider corrosion protection alternatives to hot-dip galvanizing

- Relied too heavily on general ASTM guidance for contract specifications versus project-specific special provisions for steel hardness, toughness, and material testing
Findings – Owner & Contractor

- Should have provided better coordination between the design and construction teams to ensure adequate material testing for hydrogen embrittlement.
Findings – Owner

- Failed to retain complete records in an easily retrievable format for new East Span contracts
Looking Forward
Rendering of Selected Steel Saddle Option
Status of Retrofit

• Fabrication on-going at XKT Engineering on Mare Island in Vallejo, CA and Steward Machine Co. in Birmingham, AL.
• Field preparation on-going with machining of shear key bases and concrete preparation of Pier E2 cap.
Retrofit Schedule & Bridge Opening

- Contractor forecasts shear key retrofit completion by December 10, 2013

- TBPOC will select bridge opening date based on retrofit completion, weather windows, and traffic impact

- Bridge opening may not coincide with Monday holiday weekend and will involve shorter advance notice
# All Other Rods Performing As Designed Since Tensioning

<table>
<thead>
<tr>
<th>Item #</th>
<th>Fabricator</th>
<th>End of Fabrication</th>
<th>Tension or Loading Complete</th>
<th># of Rods Installed</th>
<th># of Fractured Rods After Tensioning</th>
<th>Days Under Tension Through July 1, 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dyson</td>
<td>Sep 2008</td>
<td>Mar 2013</td>
<td>96</td>
<td>32</td>
<td>Rods began failing after 3 days of tensioning</td>
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<td>2</td>
<td>Dyson</td>
<td>Mar 2010</td>
<td>Apr 2013</td>
<td>192</td>
<td>0</td>
<td>91</td>
</tr>
<tr>
<td>3</td>
<td>Dyson</td>
<td>Mar 2010</td>
<td>Sep 2012</td>
<td>320</td>
<td>0</td>
<td>295</td>
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<tr>
<td>4</td>
<td>Dyson</td>
<td>Mar 2010</td>
<td>Sep 2012</td>
<td>224</td>
<td>0</td>
<td>292</td>
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<tr>
<td>5</td>
<td>Dyson</td>
<td>Aug 2009</td>
<td>Jun 2009</td>
<td>96</td>
<td>0</td>
<td>1,429</td>
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<td>6</td>
<td>Dyson</td>
<td>Dec 2009</td>
<td>Jan 2010</td>
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<td>1,245</td>
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<td>7</td>
<td>Dyson</td>
<td>Nov 2011</td>
<td>Sep 2012</td>
<td>274</td>
<td>0</td>
<td>278</td>
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<td>8</td>
<td>Dyson</td>
<td>Jul 2010</td>
<td>Jul 2012</td>
<td>25</td>
<td>0</td>
<td>351</td>
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<tr>
<td>9</td>
<td>Dyson</td>
<td>Jan 2011</td>
<td>Jul 2012</td>
<td>108</td>
<td>0</td>
<td>351</td>
</tr>
<tr>
<td>10</td>
<td>Dyson</td>
<td>Jan 2011</td>
<td>Mar 2013</td>
<td>90</td>
<td>0</td>
<td>97</td>
</tr>
<tr>
<td>11</td>
<td>Dyson</td>
<td>Oct 2011</td>
<td>Jul 2012</td>
<td>4</td>
<td>0</td>
<td>334</td>
</tr>
<tr>
<td>12</td>
<td>Vulcan Threaded Products</td>
<td>Feb 2007</td>
<td>Mar 2011</td>
<td>388</td>
<td>0</td>
<td>821</td>
</tr>
<tr>
<td>13</td>
<td>Vulcan Threaded Products</td>
<td>Feb 2007</td>
<td>Mar 2011</td>
<td>36</td>
<td>0</td>
<td>821</td>
</tr>
<tr>
<td>14</td>
<td>Dyson</td>
<td>Jun 2010</td>
<td>May 2010</td>
<td>32</td>
<td>0</td>
<td>1,125</td>
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<tr>
<td>15</td>
<td>Dyson</td>
<td>May 2010</td>
<td>Apr 2012</td>
<td>18</td>
<td>0</td>
<td>443</td>
</tr>
<tr>
<td>16</td>
<td>Dyson</td>
<td>Oct 2012</td>
<td>Feb 2013</td>
<td>24</td>
<td>0</td>
<td>142</td>
</tr>
<tr>
<td>17</td>
<td>Dyson</td>
<td>Jun 2009</td>
<td>In Design</td>
<td>43</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
Improved Microstructure

Failed 2008 Rod

Essentially martensitic structure.
The center region did not fully transformed into martensite

Other Rod

Essentially martensitic structure.
Improved Microstructure

Failed 2008 Rod
Brittle Failure in Field

Other Rod
Ductile Failure in Lab Test
Improved Hardness

Failed 2008 Rod

Other 3” Rods

Rockwell C Hardness

Survey – 3” Rods

- Item 9 (20 rods)
- All 3” Rods (686 rods)
- Item 12 (226 rods)
- Item 3 (287 rods)
- Item 15 (8 rods)
- Item 2 (138 rods)
- Item 16 (12 rods)
+ ASTM Req.
3D Rendering of Stress Corrosion Test Platform

- Test platform being fabricated at Pier 7.
- First tests to begin the week of July 22, 2013
Critical Stress Intensity vs. Surface Hardness
Townsend Formulation
(Based on Rod by Rod Data from Test 1: June 21, 2013)

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Construction</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Replace Before Opening (96)</td>
<td>Replace After Opening (740)</td>
</tr>
<tr>
<td>E2</td>
<td>1. Shear Key Anchor Rods (bottom) (96)*</td>
<td>2. Bearing &amp; Shear Key Anchor Rods (bottom) (192)</td>
</tr>
<tr>
<td></td>
<td>* replaced by steel saddle retrofit</td>
<td>3. Shear Key Rods (top) (320)</td>
</tr>
<tr>
<td>Anchorage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom of Tower</td>
<td>12. Tower Anchor Rods (Type 1) (388)</td>
<td>13. Tower Anchor Rods (Type 2) (36)</td>
</tr>
<tr>
<td>East Cable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Dehumidification is already in place for the Top of Tower, Bottom of Tower and Main Cable Anchorage.
New Bridge versus Old Bridge
Comparison of Ground Accelerations

Spectral Acceleration (gravity)

- 'SFOBB East Span 1,500-Year FN Soft Rock
- Original (1930) SFOBB Design (10% gravity)
- 1989 Loma Prieta Earthquake - Yerba Buena Island (rock motion)
Bottom Line

- It is safe to open the new East Span after replacing the capacity lost by the failed 2008 rods.

- The risk of near-term hydrogen embrittlement has passed.

- The potential for longer-term stress corrosion can be managed safely and effectively after SAS is placed into service.