Shear Key S1 & S2 Design Alternatives and Testing of A354BD

Seismic Safety Peer Review Panel
May 6, 2013
Self Anchored Suspension Bridge

Self-Anchored Suspension Bridge

Pier W2

Pier T1 (Tower)

Mean Sea Level — Elev 0.000

Pier E2

To San Francisco

To Oakland

Suspending Type

Cable

Bridge

Pier W2W

Pier E2W

Tower
East Bent Elevation
• Shear key design forces are determined based on the larger of:
  • 1.4 x Safety Evaluation Earthquake (Envelope from 6SEE Time-History Analysis)
  • 1.15 x Push-Over Analysis using maximum feasible material strengths:
    – Concrete: f'ce = 1.7 f'c
    – Rebar: fye = 1.3 fy
### Primary Function

<table>
<thead>
<tr>
<th>Force</th>
<th>Component</th>
<th>B1</th>
<th>S1</th>
<th>B3</th>
<th>S3</th>
<th>S4</th>
<th>B2</th>
<th>S3</th>
<th>B4</th>
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</tr>
</tbody>
</table>

All bearings and shear keys are functional.

*Load factor for demand = 1.4

### Backup (Redundancy) Function

<table>
<thead>
<tr>
<th>Force</th>
<th>Component</th>
<th>B1</th>
<th>S1</th>
<th>B3</th>
<th>S3</th>
<th>S4</th>
<th>B2</th>
<th>S3</th>
<th>B4</th>
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<td>X</td>
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<tr>
<td>TRANSVERSE**</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All bearings and shear keys are functional.

Shear keys are assumed non-functional.

**Load factor for demand = 1.0
E2 Bearing and Shear Key
Broken Bolt Location

Location of Breaks
Shear Key S1 & S2: Alternatives Considered

- Alternative A: Replace Rods in Kind
- Alternative B: Dowel Option
- Alternative C1: Concrete Jacket (Single Layer PT)
- Alternative C2: Concrete Jacket (Double Layer PT)
- Alternative BD1: Dowel / Steel Collar Option
- Alternative BD2: Diaphragm Option
Alternative BD2 Overview

- Shear Key Lower Stub
- Steel Tie Down Frame
- Bearing
- Transverse PT Grillage with Concrete Cover
Alternative C2 Overview

Shear Key

Steel Saddle

Bearing

Concrete Jacket Wall (for PT tendons/anchors)
Alternative BD2

Applied Shear:
- Trans: 42.5MN
- Longi: 19.0MN

Reaction:
- Friction due to Vertical PT
- Friction at the bottom of Shearkey (not counted in design)
Alternative BD2

Applied Shear:
- Trans: 42.5MN
- Longi: 19.0MN
- Moment Arm: 1.0m

Reaction:
- Tie Down Frame Vertical and Horizontal Restraint
- Shear Key Bearing against Pier

CROSS SECTION AT SHEAR KEY
At Each Anchorage Zone:

- **Vertical PT:**
  - 5 Tendons
  - 27-0.6 in Strand
  - Stressed to: 0.7 fpu
  - PT Force: 5.0 MN

- **Top Transverse PT:**
  - 3 Tendons per group
  - 3 groups
  - 7-0.6 in Strand
  - Stressed to: 0.7 fpu
  - PT Force: 1.3 MN/group

- **Bottom Transverse PT:**
  - 5 Tendons
  - 9-0.6 in Strand
  - Stressed to: 0.7 fpu
  - PT Force: 1.6 MN
Alternative BD2

Layer 6

Layer 7

Layer 9

1 1/2" Ø A325 Threaded Rods

2 2" Ø A354 GR BC

Bolts in Tapped Holes

1 3" Steel Plates

A704 GR 50

Milled to 2mm Flatness

Hardened Nuts

in Retainers

KEY TO LAYERING

NTHS

2120

1600

6 Splice, Typ

2840

1600

Typ
Alternative BD2: Analysis Model

Maximum Displacements

- Top Grillage:
  - x: 1 mm
  - y: 0 mm
  - z: 0 mm

- Bottom Grillage:
  - x: 1 mm
  - y: 2 mm
  - z: 0 mm
Alternative BD2: Shear Key Von Mises Stress

Black Denotes Stress > 345 MPa

Coupon Test Yield Stress Values
- 380 MPa
- 391 MPa
- 403 MPa
- 452 MPa
Alternative BD2: Tie Down Frame Von Mises Stress
Alternative BD2: 
Contact Btw Shear Key and Pier Cap

Contact Between Shear Key and Pier Cap
Black = No Contact

Maximum Displacements
• Shear Key Base:
  x: 2 mm
  y: 6 mm
  z: 2 mm
Alternative BD2: Anchorage Zone Concrete

Vertical Section Cut at CL of Vertical Tendon
Alternative BD2: Vertical Tendon Stress

Vertical PT:
- Initial Stress: 1316MPa = 0.71fpu
- Stress Range Under SEE Load
  - Max: 1330MPa = 0.72fpu
  - Min: 1300MPa = 0.70fpu
Alternative C2 Overview

- Shear Key
- Steel Saddle
- Bearing

Concrete Jacket Wall (for PT tendons/anchors)
Alternative C2

Applied Shear:
- Trans: 42.5MN
- Longi: 19.0MN
- Moment Arm: 1.0m
Alternative C2

- **Vertical PT:**
  13x19-0.6 Dia Tendons (each side of shear key base)

- **Top Longitudinal Tendons:**
  7x9-0.6 Dia Tendons (each side of cap beam)

- **Bottom Longitudinal Tendons:**
  4x9-0.6 Dia Tendons (each side of cap beam)

- **Transverse Tendons:**
  6x12-0.6 Dia Tendons (each side of pier)

- **Through-cap Tendons:**
  9x12-0.6 Dia Tendons (as shown)
Alternative C2

TOP PLAN OF CAP BEAM
Alternative C2

BOTTOM PLAN OF CAP BEAM
Alternative C2

KEY PLAN

SIDE VIEW

UPPER SADDLE DETAILS

SECTION VIEW
Alternative C2

KEY PLAN

LOWER SADDLE DETAIL

SIDE VIEW

SECTION VIEW
Alternative C2: Analysis Model

3D solid elements
Linear Materials
- $E_{\text{steel}} = 200,000$ Mpa
- $E_{\text{concrete}} = 37,400$ Mpa
- $E_{\text{grout}} = 67,700$ Mpa (composite w/saddle)

Controlling Seismic Load
= 1.4 x Concurrent SEE Loads
= 42.5 MN Transv. + 19 MN Long.

PT considered to be grouted.
Constraints of PT to solid elements hidden for clarity
Alternative C2: Shear Key Contact Conditions

Friction Coefficients:
- Steel-Concrete: 0.67
- Steel-Steel: 0.50

Contact Condition:
- Steel-Saddle to ShearKey Lower Housing
- ShearKey Lower Housing to Concrete Pier Cap
- Glue Mesh Steel-Saddle to PT Grout
- PT Grout with added stiffness
- Glue Mesh PT Grout to Pier Cap
- Steel Saddle
Alternative C2: Deformed Shape

Shear Key Displacements
Longitudinal = 2mm
Transverse = 6mm
Vertical = 4mm
Alternative C2: Contact of Shear Key/Pier Cap

Contact Between Shear Key and Pier Cap
Black = No Contact
Maximum Separation 3mm
Alternative C2: Contact of Steel Saddle/Shear Key

Contact Between Steel Saddle and Shear Key
Black = No Contact
Alternative C2: Shear Key Von Mises Stress

Black Denotes Stress > 345 MPa

Coupon Test Yield Stress Values
- 380 MPa
- 391 MPa
- 403 MPa
- 452 MPa
Alternative C2: PT Stresses

1500/1860 = 0.81fpu

1300/1860 = 0.70fpu

AXIAL_STRESS
RST CALC
TIME 3.000

MAXIMUM
EG 1012, EL 6126, IPT 1

MINIMUM
EG 1012, EL 6126, IPT 1

PT_Stress_017

Option C: Steel Saddle Continuous Glued Dual Layer Stiff Grout Summary_017.pdf
### Design Alternatives For Shear Keys S1 and S2

<table>
<thead>
<tr>
<th>ID Tag</th>
<th>ID Text Label</th>
<th>Image</th>
<th>Major Steps</th>
<th>Major Pros</th>
<th>Major Cons</th>
</tr>
</thead>
</table>
| BD(2)  | Steel Collars | ![SteelCollars](image1.png) | 1) Procure material (PT strands/ steel plate/ bolts)  
2) Fabricate steel frame/ transverse steel grillage  
3) Tap holes in existing lower housing and prepare surface  
4) Core existing concrete and cast supplemental concrete  
5) Install steel frame and grillages  
6) Grout under steel frame and grillages  
7) Tension PT and grout  
8) Cast cover concrete | • Provide full expected earthquake safety (1500 years of recurrence interval)  
• Shear keys do not need to be removed  
• Does not require splitting the bushing | • Requires more steel fabrication (milling/ welded steel grillages/ bolted steel frame)  
• Requires multiple vertical and horizontal cores  
• Requires an alternative procedure for future bearing replacement |
| C(2)   | Prestressed Collars | ![PrestressedCollars](image2.png) | 1) Procure material (PT strands/ steel plate)  
2) Fabricate steel frame/ saddle  
3) Concrete surface preparation/ drill and bond  
4) Core existing concrete  
5) Cast concrete jacket  
6) Install steel frame/ saddle  
7) Grout under saddle  
8) Tension PT and grout | • Provide full expected earthquake safety (1500 years of recurrence interval)  
• Shear keys do not need to be removed  
• Requires fewer horizontal cores and no vertical cores  
• More economical to build  
• Less maintenance | • Requires concrete jacket  
• Requires complex saddle fabrication  
• Requires splitting of the bushing |

**Design Recommends Alternative C(2)**
SFOBB-SAS Pier E2: Bearings and Shear Keys

- S1 (80 Total)
- B1 (56 Total)
- S2 (80 Total)
- S3 (80 Total)
- B3 (56 Total)
- B4 (56 Total)
- S4 (80 Total)

- B1 (24 Total)
- B3 (24 Total)
- S2 (48 Total)
- B2 (24 Total)
- S3 (48 Total)
- S4 (48 Total)
- B4 (24 Total)
GOAL: Determine acceptable levels for sustained pre-tension loads for existing A354 BD. This goal will be reached through a combination of:

- In-Situ Hardness test of representative sample (%)
- Laboratory hardness test of representative sample (%)
- Destructive testing/chemical analysis/metalurgical analysis of a representative sample (%)
- Wet test of a representative sample (%)

In addition, the 2008 bolts are being tested (same as above)

Based on the testing program results:

- Conclude that existing A354 BD at current sustained stress levels are acceptable
- Consider reducing Pre-tension (this will require a fit-for-purpose analysis)
- Replace Rods
# E2 Shear Keys (S3 & S4) and Bearings Connection To E2 Capbeam

## Equivalent Substitution
### 192 Rod Replacement Alternatives (2010)
(To be considered in the event that test results indicate that change of existing rods is advisable)

<table>
<thead>
<tr>
<th>ID Tag</th>
<th>ID Text Label</th>
<th>Nominal Diameter (inch)</th>
<th>Minimum Strength (Fu) [ksi]</th>
<th>Prestress (ratio of Fu)</th>
<th>Pre-Tension Load per Bolt [kips]</th>
<th>Major Pros</th>
<th>Major Cons</th>
<th>Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ASTM A354 BD Rods w/ Supplementary Requirements</td>
<td>3</td>
<td>140</td>
<td>0.7 Fu</td>
<td>585</td>
<td>- Does not require fit-for-purpose evaluation</td>
<td>- Additional requirements above ASTM standards - May require removal of grout in pipe sleeve for rod replacement</td>
<td>- Estimated at 3-4 months</td>
</tr>
<tr>
<td>2</td>
<td>ASTM A354 BC Rods</td>
<td>3.5</td>
<td>115</td>
<td>0.61 Fu</td>
<td>585</td>
<td>- Avoids use of high strength material</td>
<td>- Requires machining of bearing bottom housing for larger spherical washer and nut assembly (32 locations) - Requires re-evaluation of the bearing bottom housing by FEM analysis to confirm if it is fit-for-purpose - Requires reaming of holes of the bearing bottom housing and the shear key bottom housing by 12mm for larger rod diameter (192 locations) - Larger diameter bolt removes 12mm of the available tolerance for fit-up - Requires removal of grout pipe sleeve for larger diameter rod. Requires modifications to jacking equipment</td>
<td>- Estimated at 3-4 months</td>
</tr>
<tr>
<td>3</td>
<td>DYWIDAG Bars</td>
<td>3” (3-15/64 max)</td>
<td>150</td>
<td>0.57 Fu</td>
<td>585</td>
<td>- Proprietary alloy and chemistry (strength meets ASTM A722; however, 3” rods are not covered under ASTM A722)</td>
<td>- Sole-source - No standard spherical nuts, washers, and dished plate; but can be designed and manufactured - Requires machining of bearing bottom housing for higher spherical washer and nut assembly (32 out of 96 locations) - Requires re-evaluation of the bearing bottom housing by FEM analysis to confirm if it is fit-for-purpose - Requires reaming of holes of the bearing bottom housing and the shear key bottom housing by 4mm for larger rod diameter (192 locations) - Requires removal of grout in pipe sleeve for larger diameter rod. Require modifications to jacking equipment</td>
<td>- Estimated at 3 to 4 plus weeks</td>
</tr>
<tr>
<td>4</td>
<td>Williams Rod</td>
<td>3” (3-3/64 max)</td>
<td>150</td>
<td>0.60 Fu</td>
<td>581</td>
<td>- Proprietary alloy and chemistry (strength meets ASTM A722; however, 3” rods are not covered under ASTM A722)</td>
<td>- Sole-source - Requires machining of bearing bottom housing for higher spherical washer and nut assembly (32 out of 96 locations) - Requires re-evaluation of the bearing bottom housing by FEM analysis to confirm if it is fit-for-purpose - Requires reaming of holes of the bearing bottom housing and the shear key bottom housing by 4mm for larger rod diameter (192 locations) - Requires removal of grout in pipe sleeve for larger diameter rod. Requires modifications to jacking equipment</td>
<td>3 to 4 weeks</td>
</tr>
<tr>
<td>5</td>
<td>Prestressing Strand</td>
<td>16 strands</td>
<td>270 before losses</td>
<td>0.44 Fu after losses</td>
<td>585</td>
<td>- ASTM A 416</td>
<td>- At bearings (48 out of 96 locations), anchor frame assemblies interfere with the upper housing - Requires fabrication of anchor frame assembly - Requires reaming of holes of the bearing bottom housing and the shear key bottom housing by 10mm to for strands - Requires re-evaluation of the bearing bottom housing by FEM analysis to confirm if it is fit-for-purpose - Does not allow for bushing replaceability for both bearings and shear keys - Requires removal of grout in pipe sleeve for strands. Requires modifications to jacking equipment</td>
<td>- strands and anchors readily available; anchor frame assembly time estimated at 6-8 weeks</td>
</tr>
</tbody>
</table>
## E2 Shear Keys (S3 & S4) and Bearings Connection To E2 Capbeam

### Potential Fit-for-purpose Substitution

192 Rod Replacement Alternatives (2010)
(To be considered in the event that test results indicate that change of existing rods is advisable)

<table>
<thead>
<tr>
<th>ID Tag</th>
<th>ID Text Label</th>
<th>Nominal Diameter (inch)</th>
<th>Minimum Strength (Fu)</th>
<th>Prestress (ratio of Fu)</th>
<th>Pre-Tension Load per Bolt (kips)</th>
<th>Major Pros</th>
<th>Major Cons</th>
<th>Lead Time</th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td>Existing ASTM A354 BD Rods w/ Reduced Pre-Tension</td>
<td>3</td>
<td>140</td>
<td>&lt; 0.7 Fu</td>
<td>&lt; 585</td>
<td>- Size of components (rods, spherical washer, spherical nut) works with existing condition</td>
<td>- Requires fit-for-purpose evaluation</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>ASTM A354 BC Rods</td>
<td>3</td>
<td>115</td>
<td>0.7 Fu</td>
<td>481</td>
<td>- Avoids use of high strength material</td>
<td>- Requires fit-for-purpose evaluation</td>
<td>- May require removal of grout in pipe sleeve for rod replacement</td>
</tr>
<tr>
<td>8</td>
<td>ASTM F1554 Gr. 105</td>
<td>3</td>
<td>125</td>
<td>0.7 Fu</td>
<td>522</td>
<td>- Size of components (rods, spherical washer, spherical nut) works with existing condition</td>
<td>- Requires fit-for-purpose evaluation</td>
<td>- May require removal of grout in pipe sleeve for rod replacement</td>
</tr>
</tbody>
</table>

SFOBB SAS Pier E2
Bearings and Shear Keys
ASTM A354 Grade BD Rods Across SFOBB-SAS
## ASTM A354 Grade BD Structural Components and Bolt Tension in Service

<table>
<thead>
<tr>
<th>ID</th>
<th>Structural Component</th>
<th>Nominal Bolt Number of Bolts</th>
<th>Diameter [in]</th>
<th>Bolt Tension @ Service % Fu (UTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shear Key Anchor Bolts - Bottom (S1/S2)</td>
<td>96</td>
<td>3</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>Shear Key Anchor Bolts - Bottom (S3/S4)</td>
<td>96</td>
<td>3</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Pier E2 Bearing Bolts - Bottom Housing (B1, B2, B3, B4)</td>
<td>96</td>
<td>3</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>Shear Key Anchor Bolts -Top (S1/S2)</td>
<td>160</td>
<td>3</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Shear Key Anchor Bolts -Top (S3/S4)</td>
<td>160</td>
<td>3</td>
<td>0.70</td>
</tr>
<tr>
<td>4</td>
<td>Pier E2 Bearing Bolts - Top Housing</td>
<td>224</td>
<td>2</td>
<td>0.70</td>
</tr>
<tr>
<td>5</td>
<td>Spherical Bearing Bushing Assembly Bolts</td>
<td>96</td>
<td>1</td>
<td>0.61</td>
</tr>
<tr>
<td>6</td>
<td>Bearing Retainer Ring Plate Assembly Bolts</td>
<td>336</td>
<td>1</td>
<td>0.40</td>
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<tr>
<td>7</td>
<td>PWS Strand Anchor Rods (Main Cable)</td>
<td>274</td>
<td>3-1/2</td>
<td>0.32</td>
</tr>
<tr>
<td>8</td>
<td>Tower Saddle Tie Rods</td>
<td>25</td>
<td>4</td>
<td>0.68</td>
</tr>
<tr>
<td>9</td>
<td>Tower Saddle Turned Rods (@ Splices)</td>
<td>100</td>
<td>3</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>10</td>
<td>Tower Saddle Grillage Bolts</td>
<td>90</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>11</td>
<td>Tower Outrigger</td>
<td>4</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>12</td>
<td>Tower Anchorage Anchor Bolts (75 Dia. Anchor Bolts)</td>
<td>388</td>
<td>3</td>
<td>0.48</td>
</tr>
<tr>
<td>13</td>
<td>Tower Anchorage Anchor Bolts (100 Dia. Anchor Bolts)</td>
<td>36</td>
<td>4</td>
<td>0.37</td>
</tr>
<tr>
<td>14</td>
<td>East Saddle Anchor Rods</td>
<td>32</td>
<td>2</td>
<td>0.10</td>
</tr>
<tr>
<td>15</td>
<td>East Saddle Tie Rods</td>
<td>18</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>16</td>
<td>Cable Bracket Anchor Rods</td>
<td>24</td>
<td>3</td>
<td>0.16</td>
</tr>
<tr>
<td>17</td>
<td>Bikepath Anchor Bolts at Pier W2</td>
<td>43</td>
<td>1-1/4</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fu (Tensile Strength) per ASTM A354-11
# Shear Key S1 & S2: 2008 Rod Testing Program

## I. Visual Examination/Observations

## II. Scanning Electron Microscopy

## III. Microstructural Examination

## IV. Hardness Testing

   a. Knoop Microhardness

   b. Rockwell C Hardness

## V. Tensile Test

## VI. Charpy V-Notch Impact Test

## VII. Chemical Analysis (Spectrochemical)

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### Test Specimens:

- S1–G1
- S2–A6

### Bearing and Shear Key Anchor Rod LD. Key:

- B1 – E8

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**Shear Key Rod LD Grid Plan View (Looking Down)**

- Grid Letter
- Grid Number

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**Bearing/Shear Key Piece Mark**

**Rod Grid Number**

**Rod Grid Letter**
Shear Key S3, S4, and Bearing B1, B2, B3, B4: 2010 Rod Testing Program

Bay Bridge Anchor Rod Testing (192 Rods)

Sample Selection:
1. In-situ testing shall be performed on all 192 anchor rods as described below.
2. Select 50 different rods for extended testing. 10 rod sample size (x 5) is larger than ASTM F1390 requirements of 7 bars for test size of LB1 to 2800 lbs.

In-Situ Testing Protocol:
1. Mark the rods selected for extended testing to identify the jacking end.
2. Install acoustic measuring devices on each of the 10 sample rods selected for extended testing.
3. Load at 137 mts in to 0.75 fs (with testing load expected to bring the final tension in the rods down to the design load of 0.75 fs).
4. Maintain the applied load for 30 days. During this period, all rods will be visually inspected daily, checking for failures.
5. NPTS will monitor the acoustic measuring equipment on the 10 rods selected for the extended testing.
6. If any rod fails prior to the 30 day testing period, extract and perform post-failure analysis as detailed below under “Extended Testing Protocol.”
7. If no rods fail within the 30 day period, extract the 10 sample rods, transport to a testing facility/yard, and load.

Extended Testing Protocol:
[Extended testing to be performed at an independent testing laboratory accredited per ISO 17025 or approved by Caltrans.]
1. Load the 10 samples to failure. The rods shall be jacked at the same ends as they were jacked during the in-situ testing.
2. Perform Cheramy V-Match tensile testing of broken rods at room temperature and at 40 degrees F.
3. Perform reduced section tensile tests (500 diameter) of the broken rods to close to the fracture surface as possible. Tensile tests to be performed as detailed in Section A.
4. Perform hardness testing (Rockwell C) and Krauss Micro-hardness of broken rods.
5. Perform chemical analysis of broken rods at the fracture area and at the shank. Chemical tests to be performed as detailed in Section B.
7. Perform Microm-structural examination of broken rods at the fractured area.

Note: It is expected that loading of the 192 bolts for 30 days will allow any existing defects to be propagated between the grain boundaries of the steel. Therefore, even if the bolts do not fail within the 30 day period, the scanning electron microscopy will provide sufficient information necessary to determine the presence of hydrogen.

Test Specimens:
• S3-E7
• S4-D7
• BC-A2
• B4-A7
Shear Key S3, S4, and Bearing B1, B2, B3, B4: 2010 Rod Wet Testing Program

**Anchor Rod Wet Test (LRFD Basis)**

The testing protocol was developed with the assistance of Dr. Mark Osmoumad, MPE, and Mr. Doug Williams, PE.

**Test Specimens:**
- ______
- ______
- ______
- ______

**Settlements:** Rod settlement shall be at settlements by the Design Joint Venture. 4 rods tested.

**Testing Protocols:** (Tested in laboratory to be performed by an independent testing laboratory accredited per AB04 or approved by Caltrans.)

1. Prior to extraction, ARSW shall move the selected rods up to 0.25% and maintain the load for 24 hours.
2. After 24 hours, the rods shall be extracted and non-destructively tested.
3. Rods shall be tested to ensure the uniformity and uniformity from the shear area.
4. Each rod shall be Ultrasonically Tested and Magnetic Particle Tested to identify any yielding nodes.
5. The results shall be transmitted to the selected testing facility where the SHEAR testing data in a 3.56 Newt/m will be performed according:

<table>
<thead>
<tr>
<th>%N</th>
<th>Load per Rod</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>263</td>
<td>48</td>
</tr>
<tr>
<td>0.60</td>
<td>314</td>
<td>48</td>
</tr>
<tr>
<td>0.70</td>
<td>448</td>
<td>48</td>
</tr>
<tr>
<td>0.80</td>
<td>569</td>
<td>48</td>
</tr>
<tr>
<td>0.90</td>
<td>710</td>
<td>120</td>
</tr>
</tbody>
</table>

* Hold time at each load step.

The testing protocol shall ensure the strain across a strain gage. In addition to a balanced load, the load is maintained and the strain is recorded.

2. After maintaining the load at 0.5% for 5 days (350 hours) of the total time, load the sample to failure.
3. Transport the fractured specimen to the failure analysis lab for further examination.
4. Perform Charpy-Hardness testing of broken rods at room temperature and at 30 degrees, per Section B.
5. Perform notched tension testing to 20% of the maximum load to measure the surface as possible. The test is to be performed as stated in Section C.
6. Perform Rockwell Hardness and Micro-hardness testing per Section D, and no closer than 100 micrometers from the ends of each rod.
7. Perform fractured analysis of broken rods at the threaded area and at the shear. Chemical tests to be performed as detailed in Section E.
9. Perform Micro-diehardness examination of broken rods at the threaded area.
10. Analyze the chemistry of the coating and provide all of components. Include information on any % or trace amount of iron and boron.

**Test Specimens:**
- ______
- ______
- ______
- ______
Pier E2 Anchor Rod “Wet” Test Test Rig Design
Pier E2 Anchor Rod “Wet” Test
General Arrangement

A354BD Rod Tensile Strength = 4.5 MN (w/ 1.2 overstrength factor)
Jack Capacity (2 jacks) = 6.3 MN
Nominal Capacity of Test Rig = 12.4 MN
Pier E2 Anchor Rod “Wet” Test General Arrangement
Tower ESW

Typical Tower Base Cross Section
(Between Elev 3,125 m and Elev 13,000 m)

Double Plate Detail (Circular Core)
(Exterior Surface of Shear Wall Only)

Double Plate Detail (Slewed Core)

Elevation View Face C

Section A-A
Tower ESW

Symmetric about C Bridge

Symmetric about Pier T1 (Tower)

Shear Wall

Tower Shaft

Location of Sample

Tower ESW

50