Resilient Seismic Upgrade of Bay Division Pipeline No. 3 at the Hayward Fault

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Water System Improvement Program (WSIP)

• City of San Francisco’s largest program
• One of the largest water infrastructure program in U.S. ($4.6 billion)
• 83 projects to upgrade, repair, and replace water infrastructure such as dams, tunnels, reservoirs, tanks, pipelines, etc.
• Enhance seismic reliability, delivery reliability, water supply reliability
Project Site Map
Site Conditions at Trace B

- Hayward fault – Right-lateral strike-slip offset
- 45-50° intersection angle with the pipelines
- Fault creep rate: 6 mm/year (1/4 inch/year)
- Primary and secondary rupture zones
- Width of primary rupture zone: 75 ft (23 m)
- Two busy highways above the pipelines
- 80-foot-wide right-of-way
- Other utility lines
Design Seismic Hazards

- Design horizontal offset at Trace B: 6.5 ft (2 m) knife-edge displacement occurring at primary rupture zone
- Site-specific probabilistic ground motion spectrum with 975-year return period
- 6 sets of scaled ground motion time histories from previous earthquakes
Performance Criteria

- **WSIP Seismic reliability goals**
  - Delivering average winter-month usage within 24 hours after a design earthquake
  - Delivering average day-demand within 30 days

- **Engineering performance goal**
  - Resilient system for uninterrupted service immediately after a design earthquake
Design Solution at Trace B – Articulated Concrete Vault

- NEW 78"Ø BDPL 3 (OUTSIDE VAULT)
- NEW 72"Ø BDPL 3 (INSIDE VAULT)

- PRIMARY RUPTURE
  - HAZARD ZONE
  - NINE 20-FT LONG 45° SKewed
  - ARTICULATED VAULT SEGMENTS

- BDPL 3 TO BE REPLACED
- BDPL 4 TO REMAIN

- SOUTH END VAULT
- NORTH END VAULT

- BALL JOINT
- SLIDING SUPPORT
- SLIDING SUPPORT

- 80-foot-wide Right-of-way

- MISSION BLVD
- GUIDED SUPPORT (4 TOTAL)
Articulated Concrete Vault

- 305-foot (100 m)-long sacrificial concrete segmented vault to accommodate fault displacement
- Nine 20-foot-long 45° parallelograms separated by 6-inch gap joints
- Two end segments that house mechanical and structural components
- 20’ (6 m) wide, 18’ (5.5 m) long, 2’ (0.6 m) thick in cross-section
Cross-section of Vault
Articulated Vault Scale Model Test
Cornell University
Soil-Structure Interaction Analysis – FLAC 3D
Pipe-in-vault Analysis
Design Solution at Trace B – Ball Joints

- NEW 78" Ø BDPL 3 (OUTSIDE VAULT)
- NEW 72" Ø BDPL 3 (INSIDE VAULT)
- HAYWARD FAULT TRACE B
- PRIMARY FUTURE HAZARD ZONE
- NINE 20-FT LONG 45° SKewed
- ARTICULATED VAULT SEGMENTS
- SOUTH END VAULT
- NORTH END VAULT
- BALL JOINT
- SLIDING SUPPORT
- SLIDING SUPPORT
- GUIDED SUPPORT (4 TOTAL)
- MISSION BLVD
Ball Joint

- 2 ball joints in total (each on either side of Trace B)
- 72-inch diameter
- Cast-iron
- 12° rotation capacity
- 125 psi operating pressure
- 200 psi transient peak pressure
Ball Joint Testing
Design Solution at Trace B – Slip Joint
Slip Joint

- 1 slip joint located at northern end
- Slip demand from fault offset, dynamic displacement, and creep
- 9-foot compression, 1-foot expansion capacities
- 37.5 inch/sec slip rate
- 125 psi operating pressure
- 200 psi transient peak pressure
Slip Joint Testing
Design Solution at Trace B – Pipe Supports
Pipe Supports

**Sliding Supports**
- 2 supports, each in front of the ball joints
- Free to slide in any horizontal direction
- React to gravity direction to reduce shear forces in the ball joints
- Sliding interface between stainless steel plate and PTFE sheet

**Guided Supports**
- 4 guide frames made of W14 shapes
- Sliding only axial longitudinal direction
- React to transverse direction to reduce shear forces and bending moment in the slip joint
- Stainless steel plate on PTFE sheet
Guided Support
Guided Pipe Section
System In Action (animated)
• Owner/Client – San Francisco Public Utilities Commission (SFPUC)
• Prime Consultant – URS Corporation
  – R. M. Czarnecki, Project Manager
  – P. Meymand, Geotechnical Engineer
  – C. Kwon, Structural Engineer
• Contribution
  – Cornell University (T. O’Rourke)
  – DGH Consulting (D. Honegger)
  – G&E Engineering Systems, Inc. (J. Eidinger)
  – Technical Advisory Panel (D. Nyman, M. O’Rourke)
  – William Lettis & Associates (S. Thompson)
• General Contractor – Steve P. Rados, Inc.
Thank you