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

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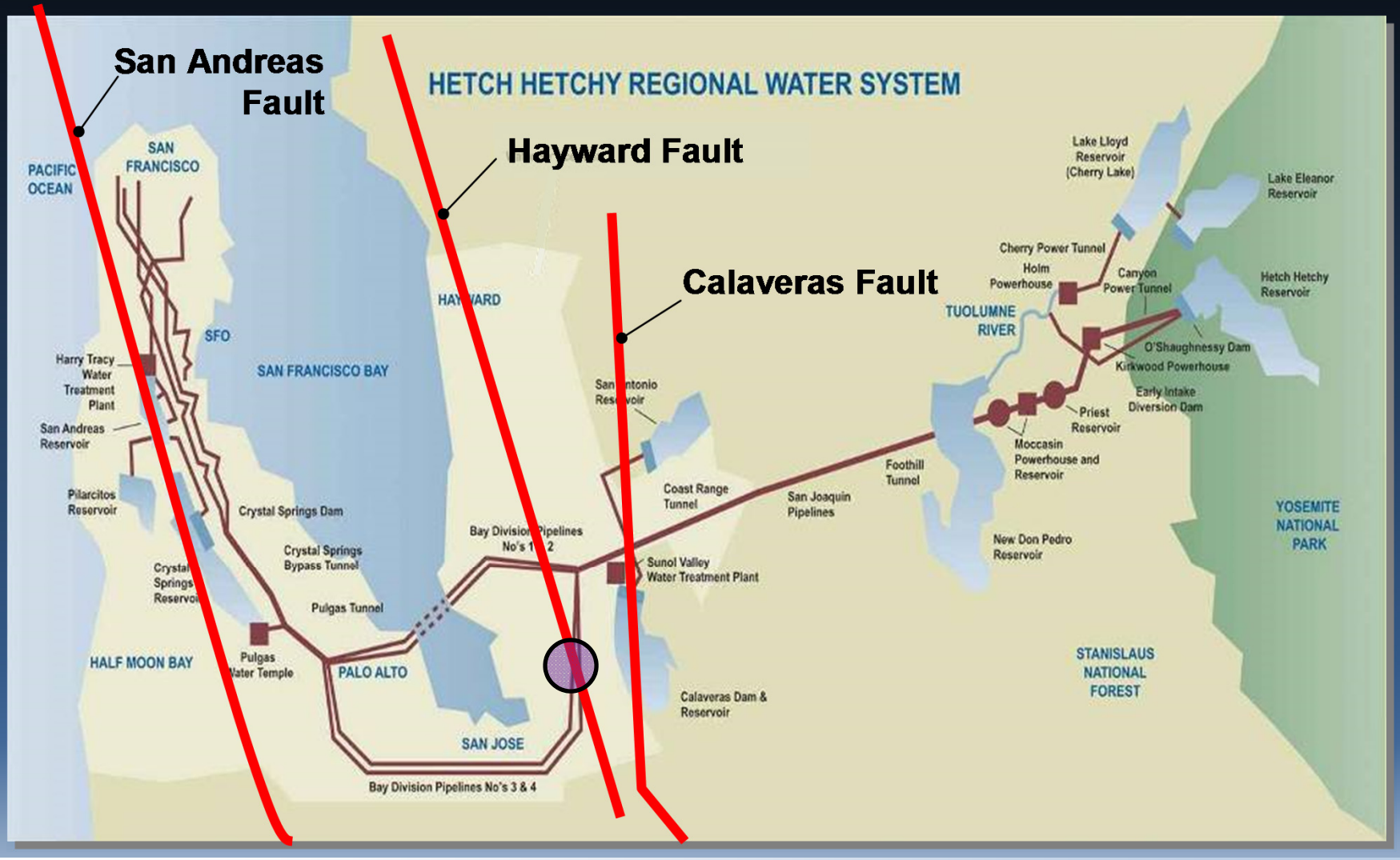
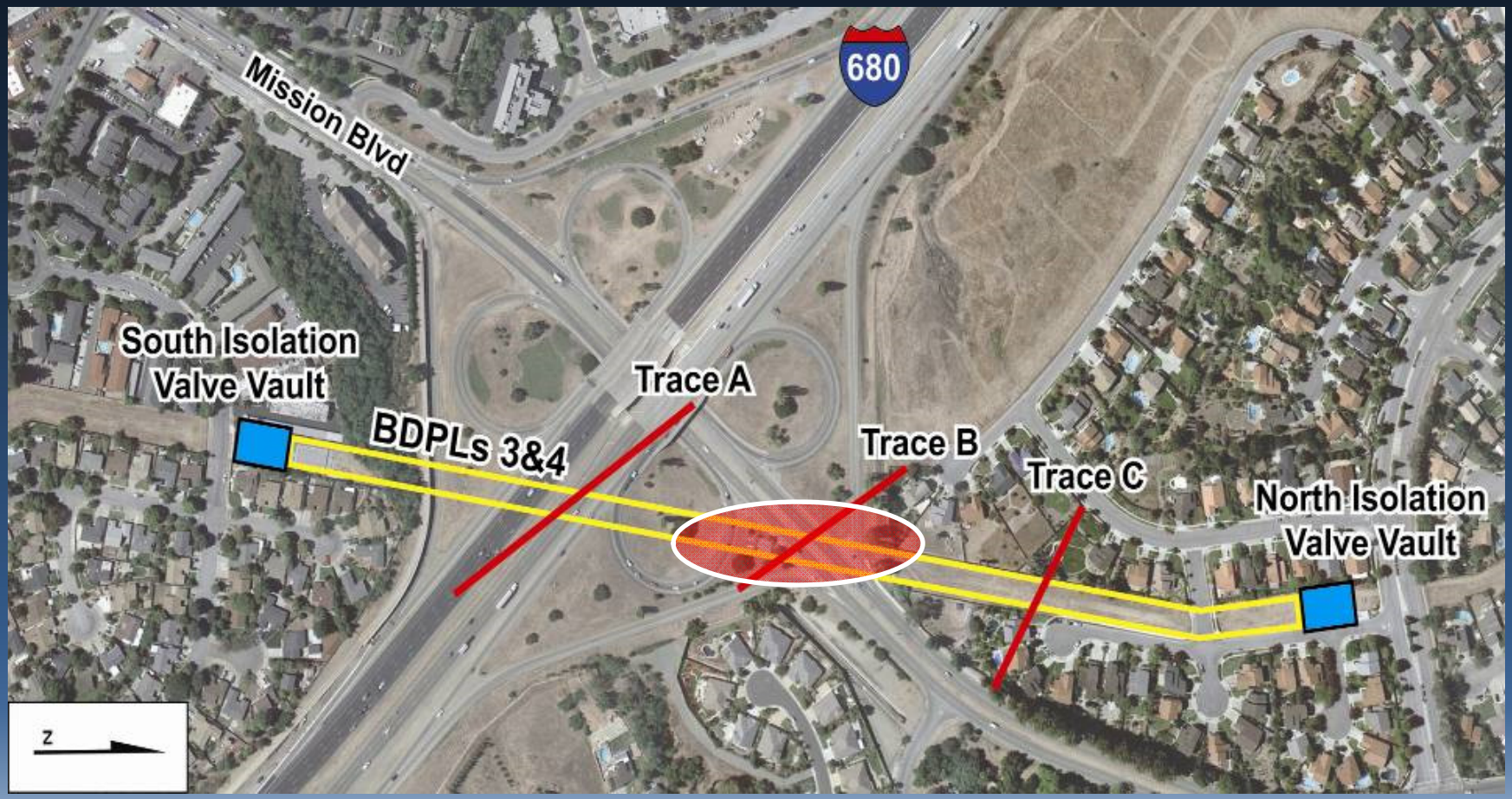
Hetch Hetchy Regional Water System



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

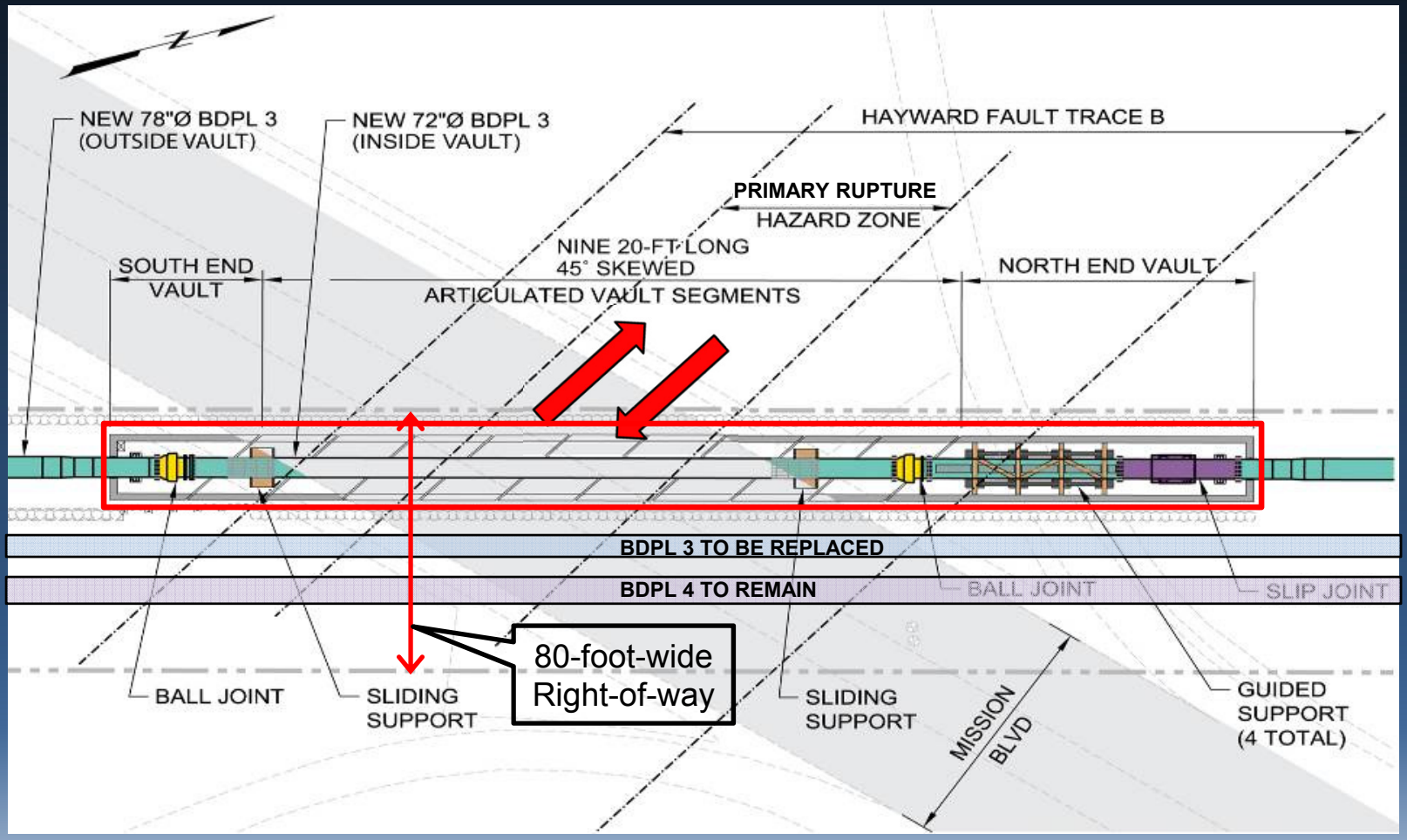
Design Seismic Hazards

- 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

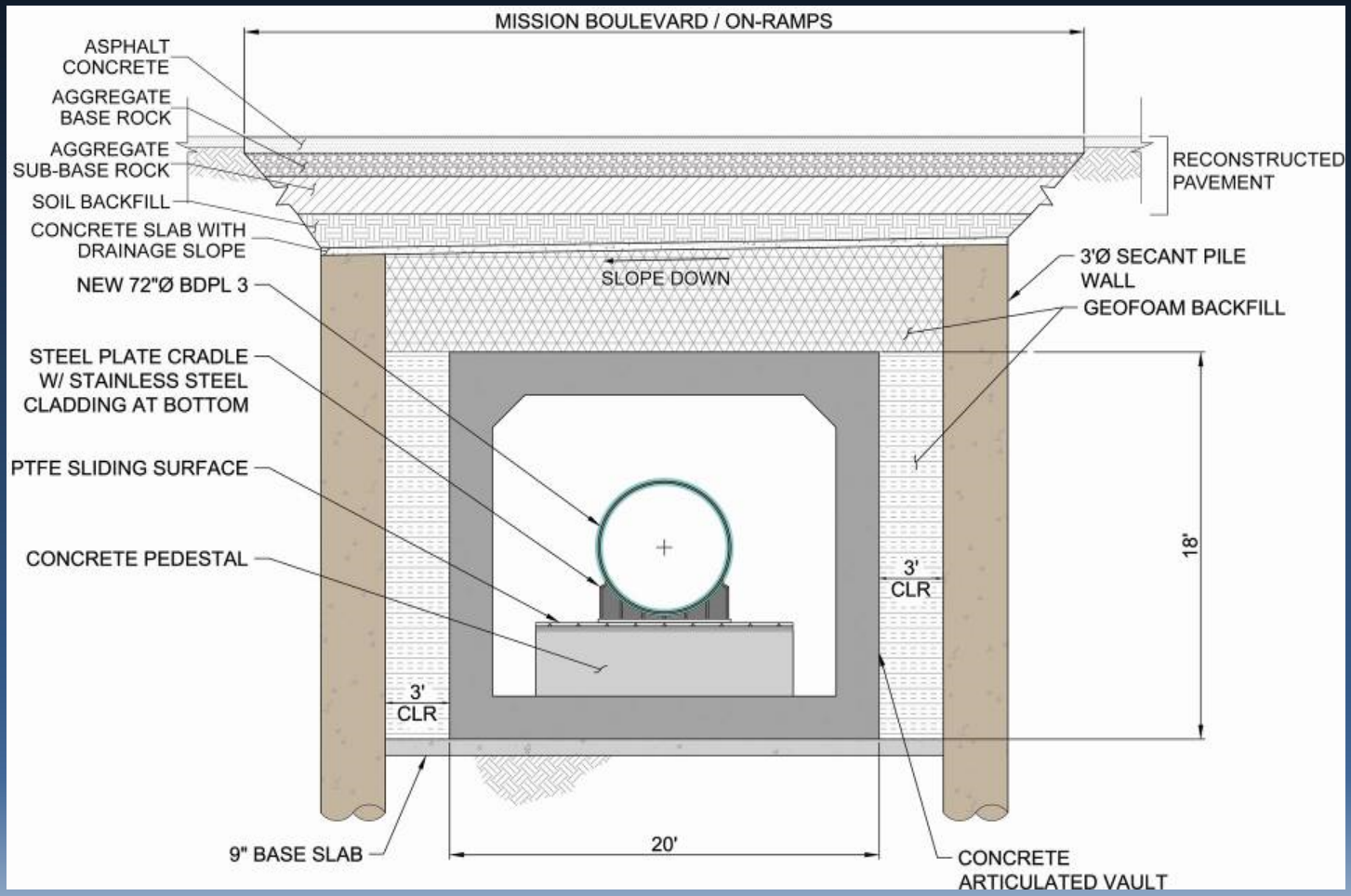
Design Solution at Trace B – Articulated Concrete Vault



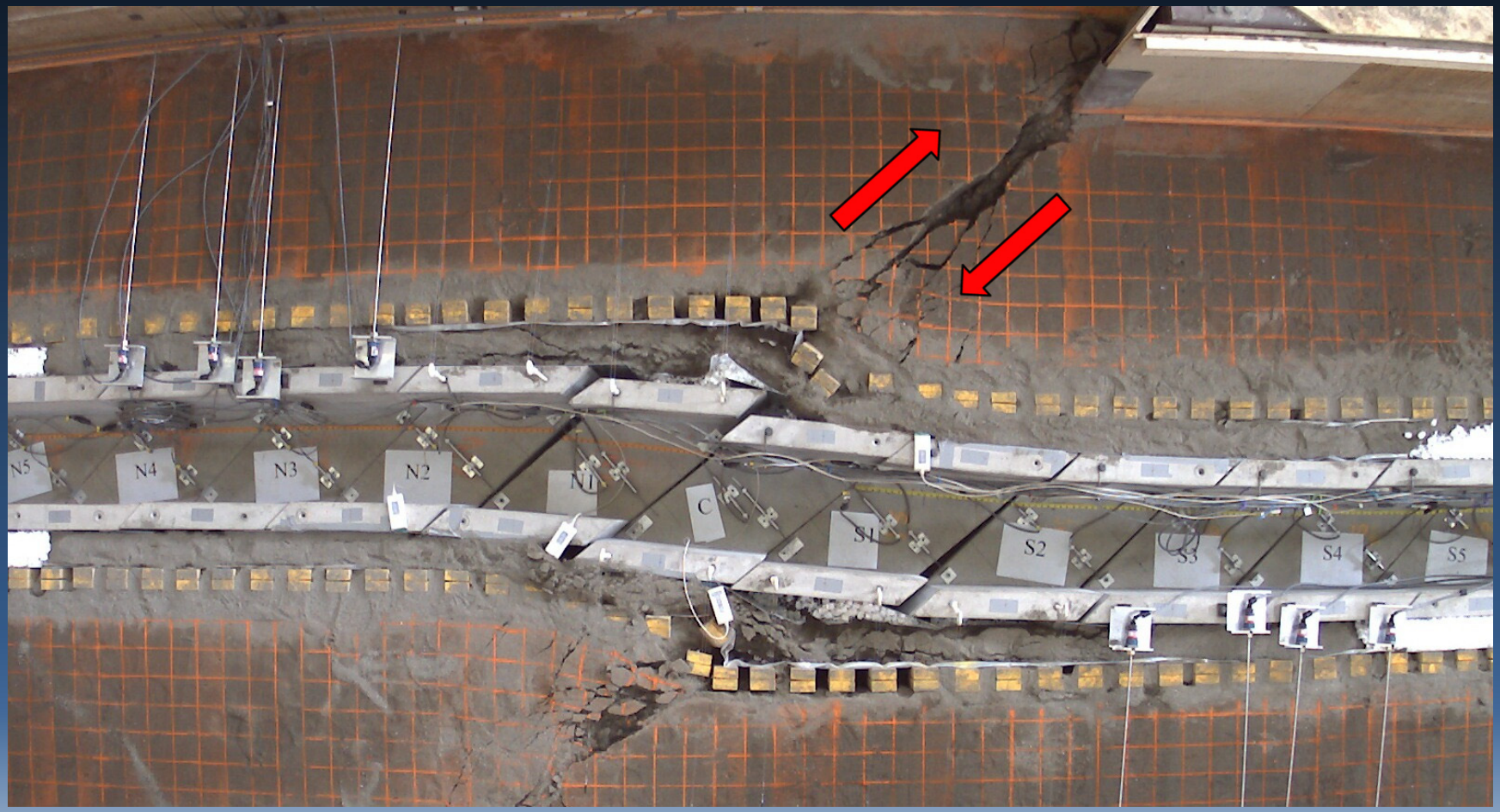
Articulated Concrete Vault

- 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

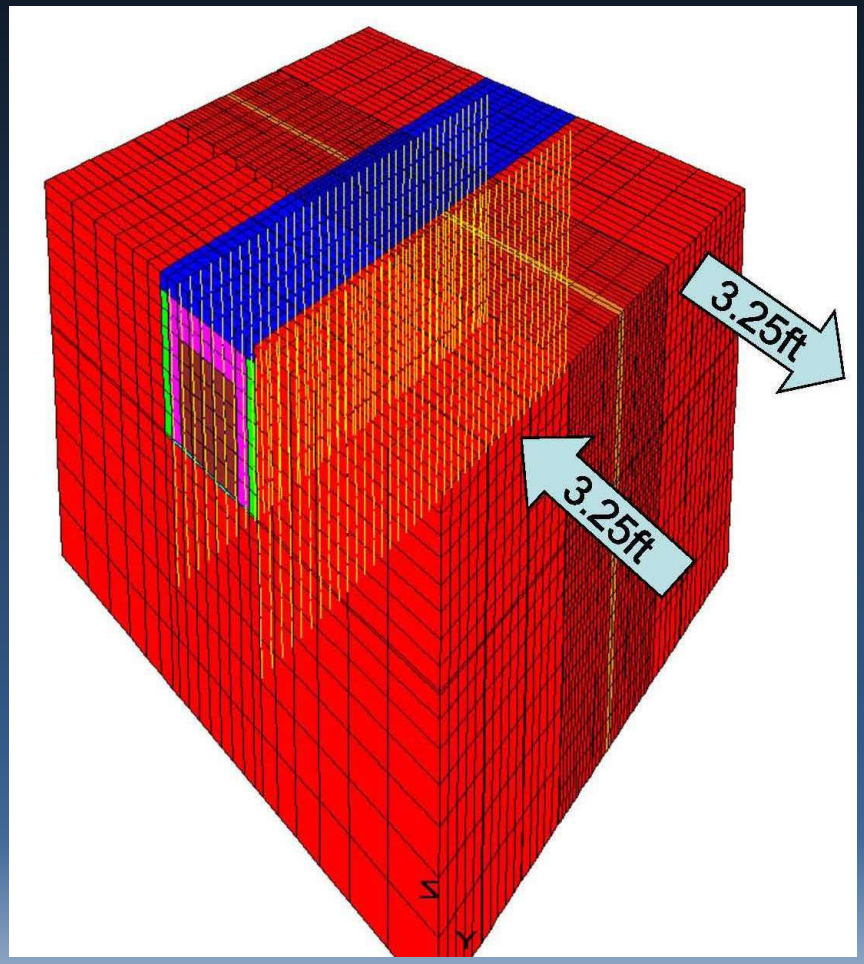
Cross-section of Vault

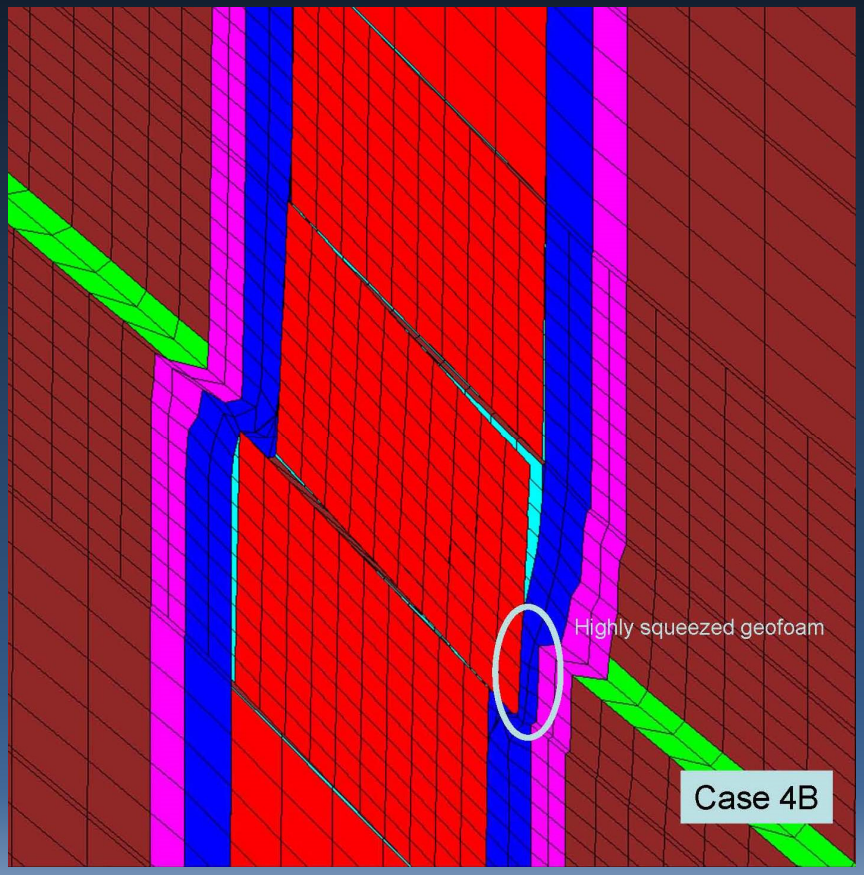


Articulated Vault Scale Model Test
Cornell University

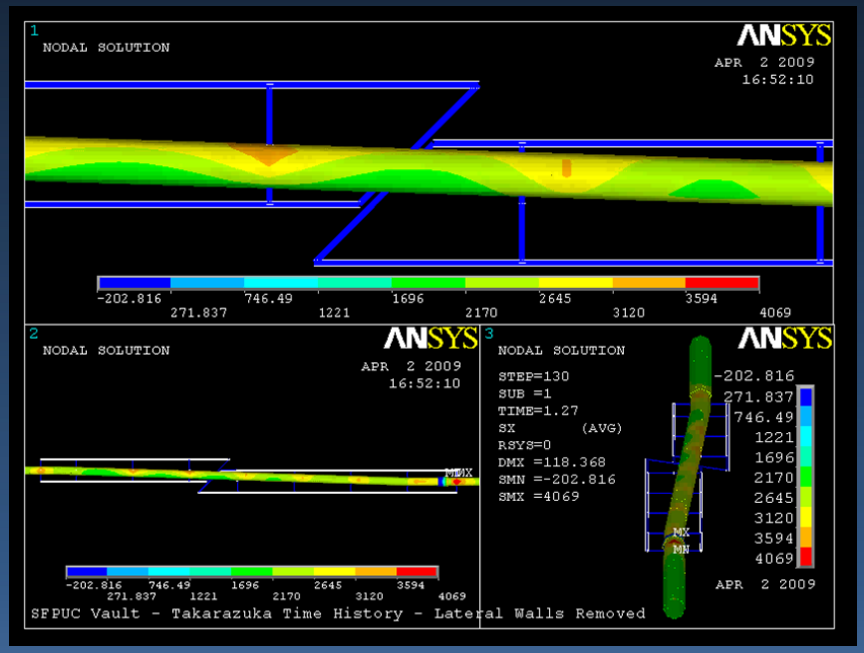


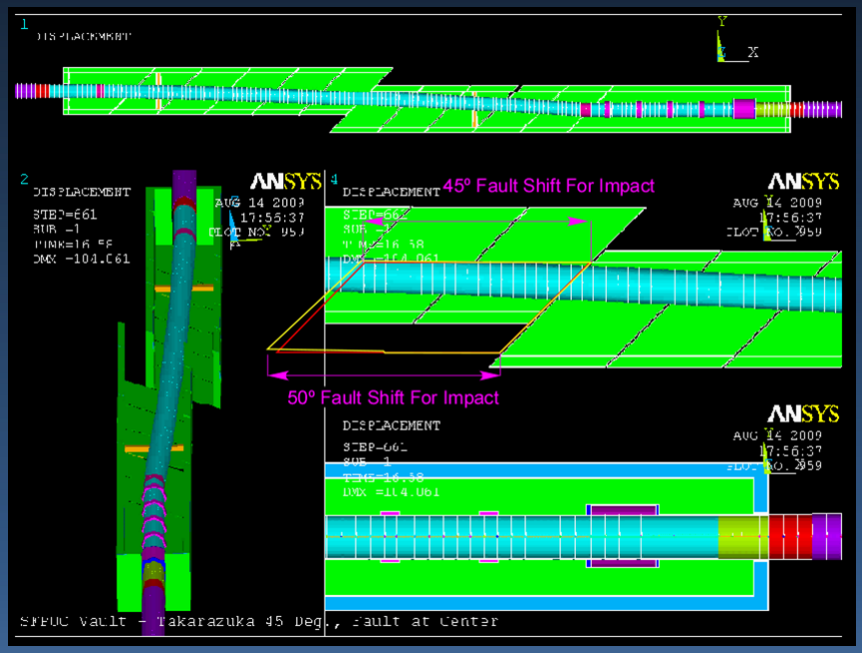
Soil-Structure Interaction Analysis – FLAC 3D



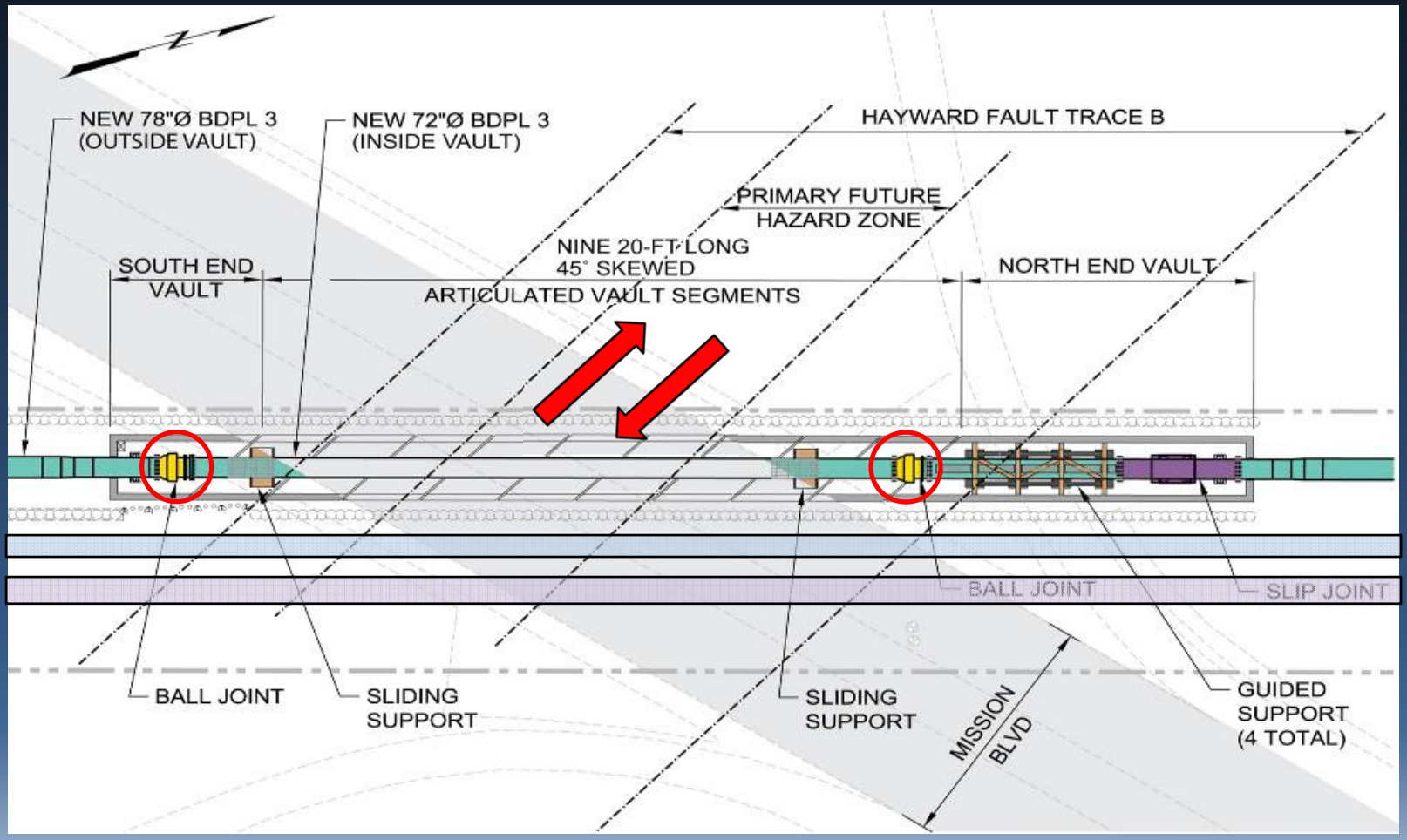


Pipe-in-vault Analysis





Design Solution at Trace B – Ball Joints

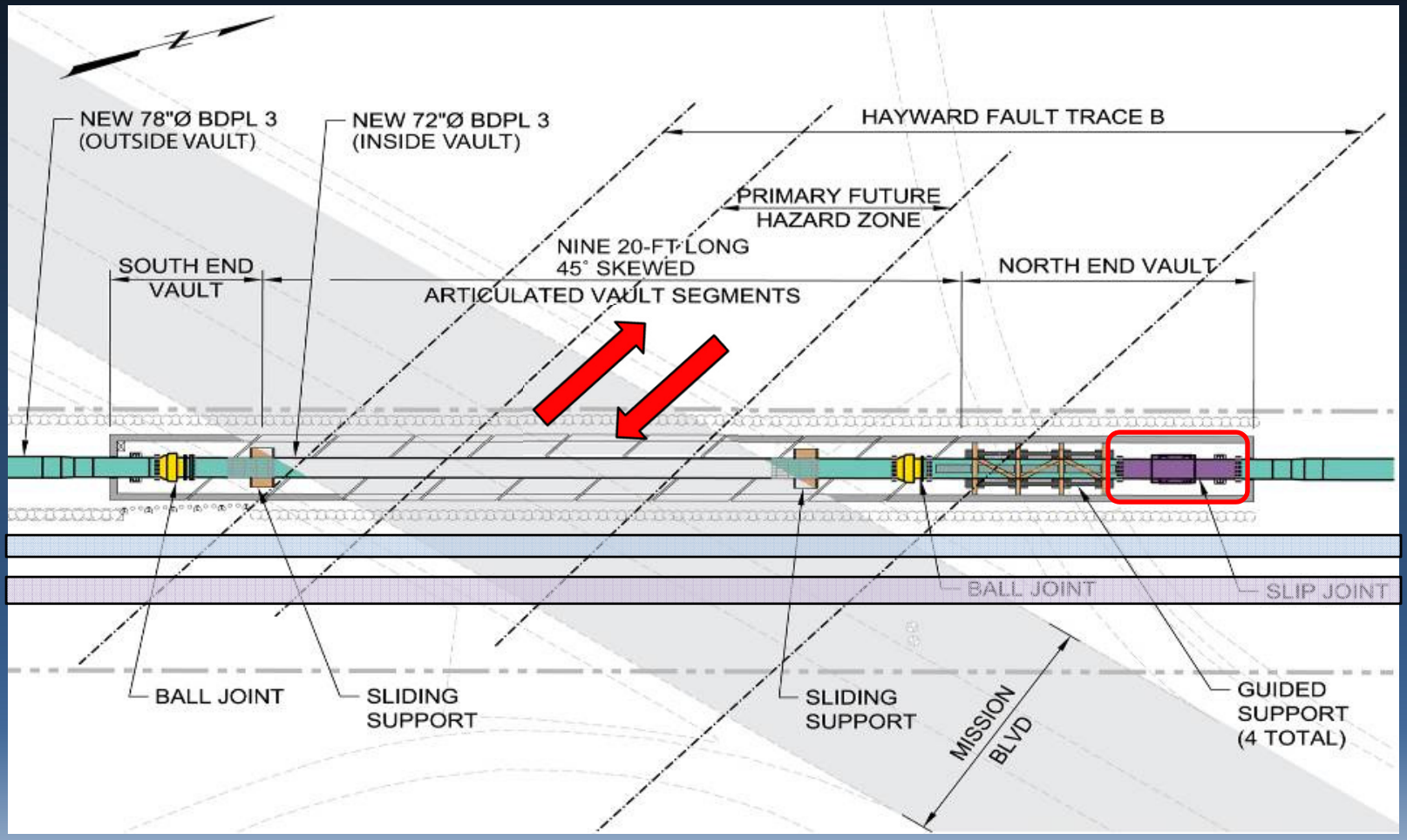


Ball Joint

- 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

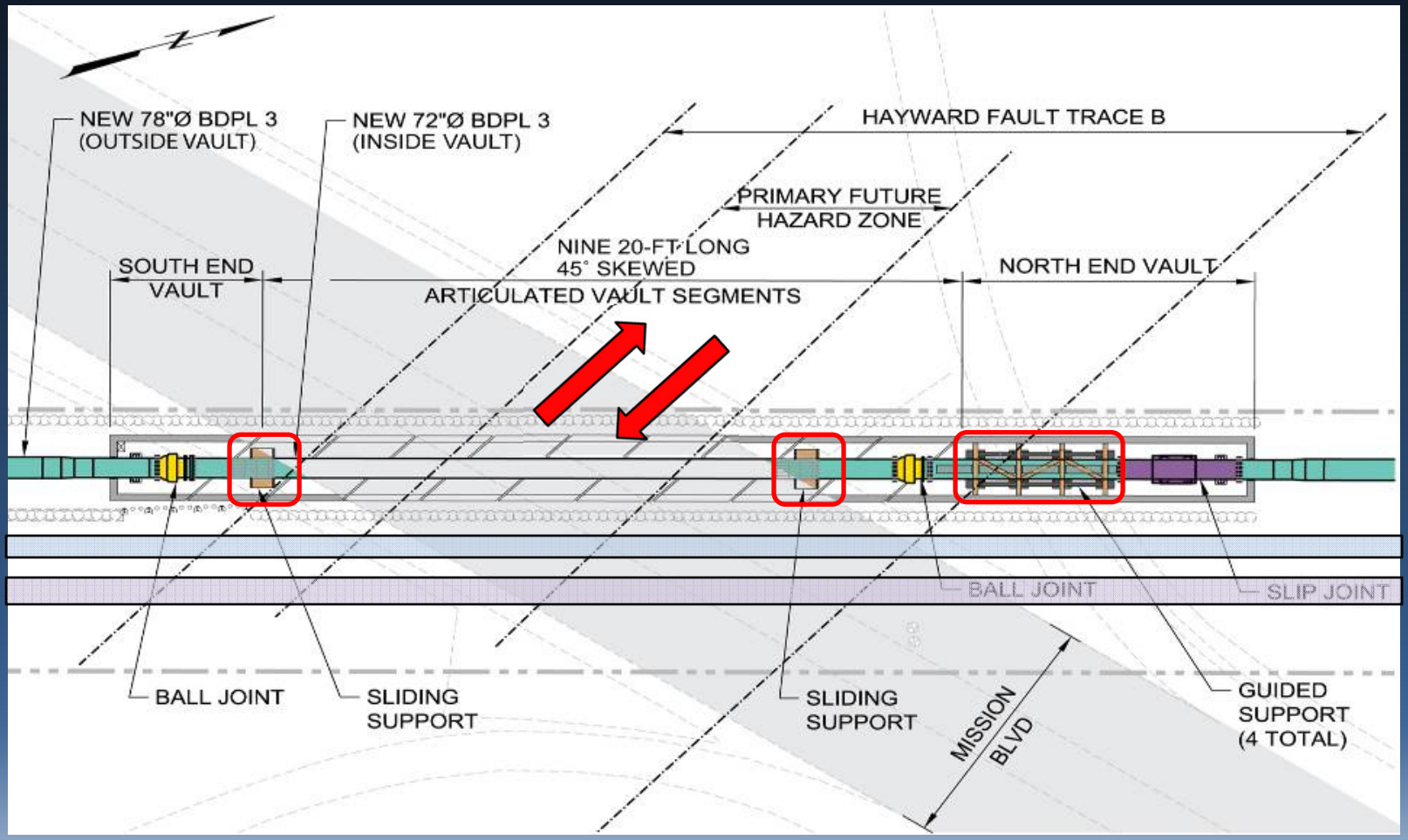


Slip Joint

- 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

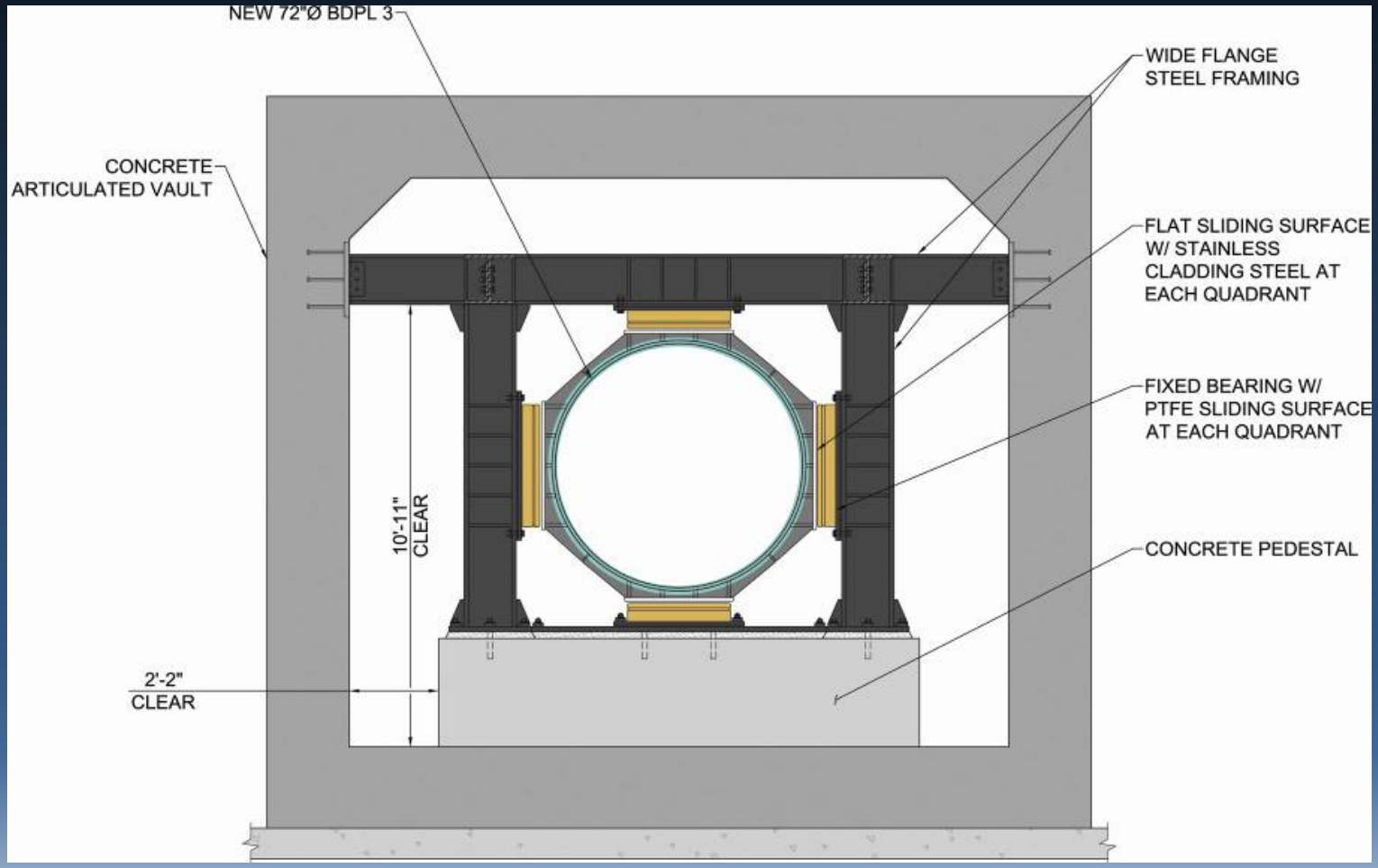
Sliding Supports

- 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