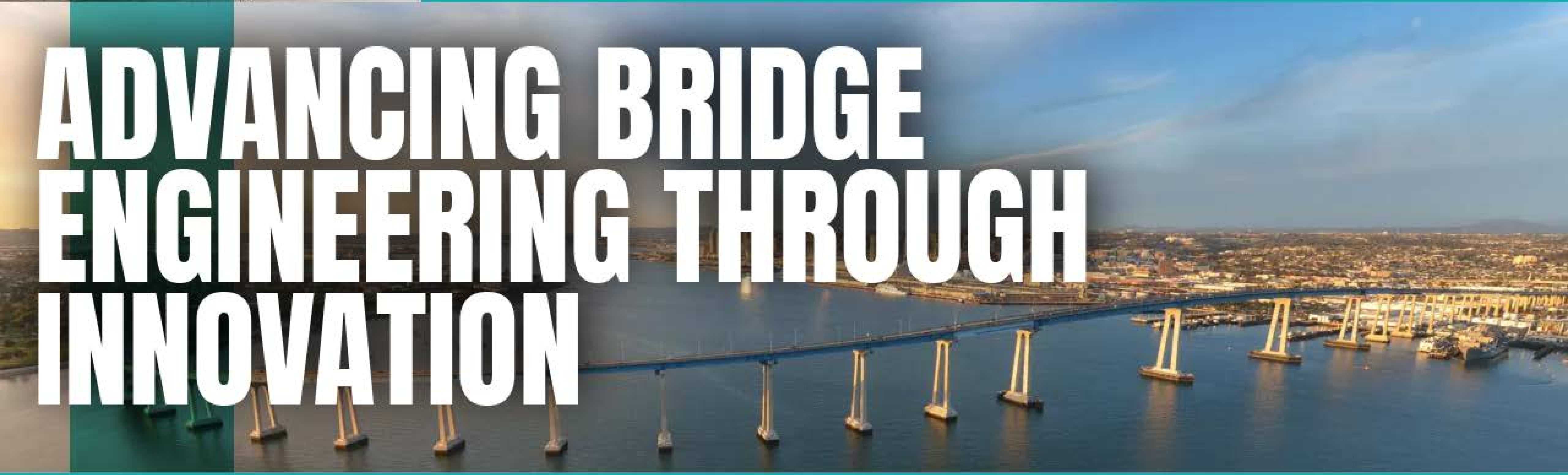
CABES

CALIFORNIA BRIDGE ENGINEERS SEMINAR



ADVANCING BRIDGE ENGINEERING THROUGH INNOVATION

Caltrans

CABES 2026

DIVISION OF ENGINEERING SERVICES

Presentation 8 - Substructure Design of the Portage Bay Bridges: Navigating Landslide, Liquefaction, and Recovery-Level Seismic Demands

Substructure Design of the Portage Bay Bridges: Navigating Landslide, Liquefaction, and Recovery-Level Seismic Demands

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Purpose and Learning Objectives

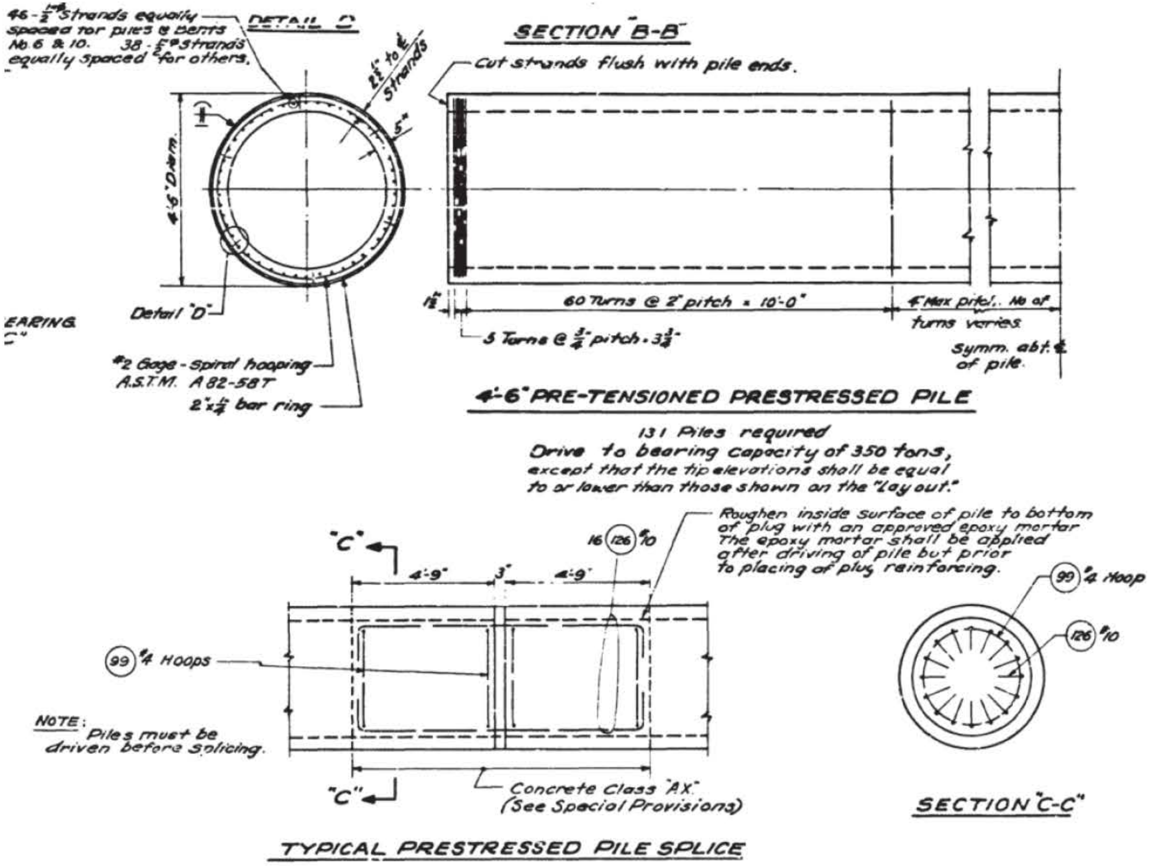
- Project Context & Structural Configuration
- Recovery-Level Seismic Philosophy
- Balanced Stiffness Across Frames
- Soil-Structure Interaction Workflow
- Landslide Compatibility for Abutments and Piers
- Detailing & Key Lessons

Existing Portage Bay Viaduct

- 29 Spans
- Similar to AASHTO Prestressed Girders
- 5 ¾” Reinforced Concrete Deck
- Reinforced Concrete Bent Caps
- Prestressed Hollow Column Piles
- Carries 2 lanes East and West
- Bifurcates at Montlake Exit Ramp Eastbound

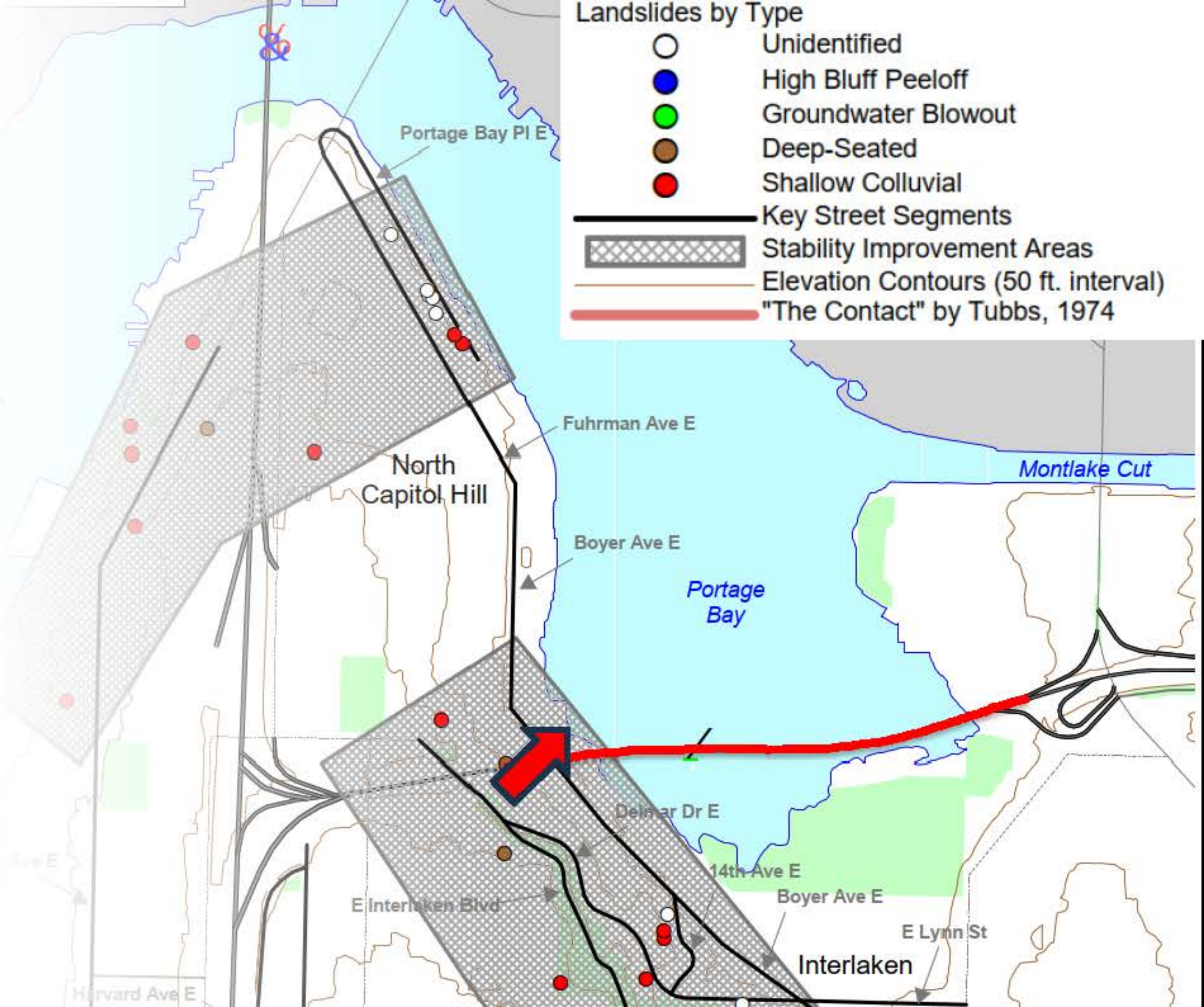
Seismically Vulnerable

- Retrofit in 1997
  - Longitudinal span restraints
    - Expansion Joints at Bents 2-5, 10, 15, 20, 24-29
- Hollow Columns
  - Retrofit below mudline impractical



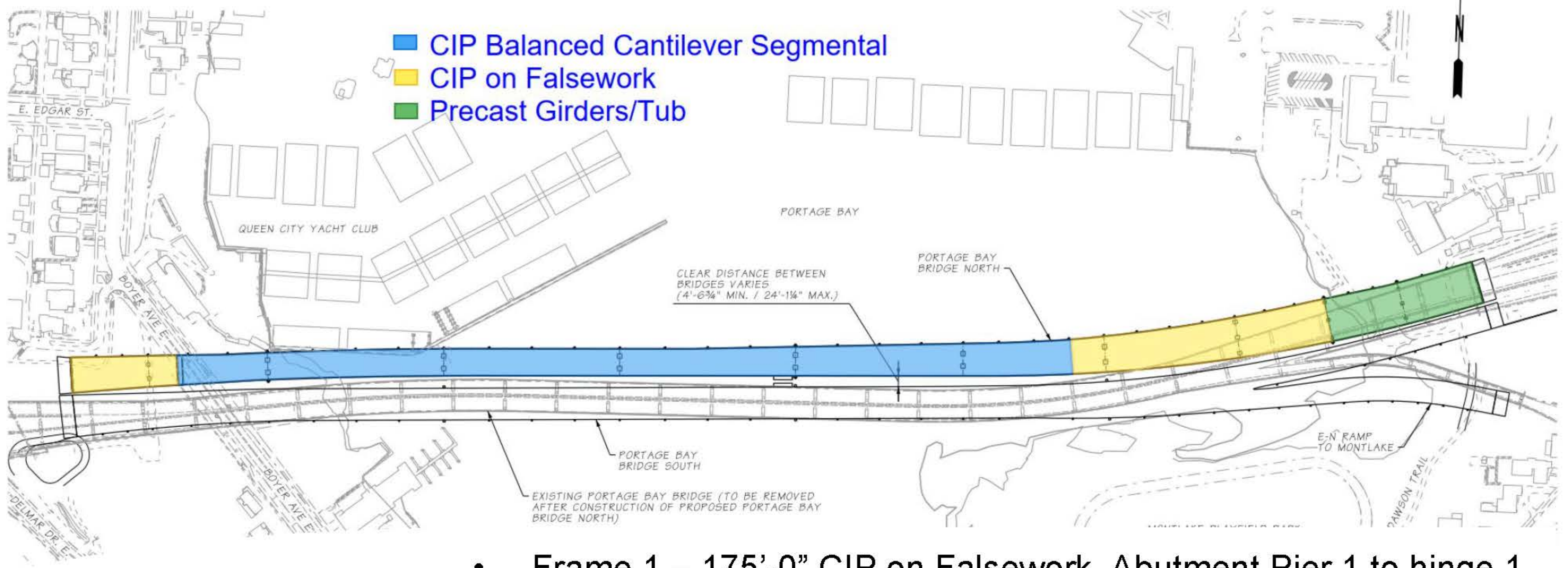
Delmar Landslide

- Deep Seated
- Debris Flow
- Moving 0"-$^1/_2$" per year
- Encompasses existing bridge piers 1-8
- Contributing Factors
  - Improper Fills
  - Steep Topography
  - High groundwater levels/seepage in colluvium on slope
  - Heavy Rainfall (triggering cause)



Bridge Concept and Layout

- Design-Build, nearly twin viaducts
- City of Seattle, WSDOT
  - Unobtrusive view, not to dominate bay
  - Ruled out Cable Stay (avoid landslide)
  - Aesthetics largely dominate
- 7 Piers allowed in water per bridge
- Required variable depth box girders
  - Limits beyond allowed other structure types
- Maximum of 4 expansion joints between abutments



Span Arrangements

- Frame 1 – 175'-0" CIP on Falsework, Abutment Pier 1 to hinge 1 in span 2
- Frame 2 – 1765'-0" of 5 Piers CIP Box Girder Semi-Balanced Cantilever Segmental
- Frame 3 – 510'-0" CIP on Falsework from hinge 2 to hinge 3 at Pier 10
- Frame 4 – 290'-7" as precast prestressed WSDOT girders

Substructure

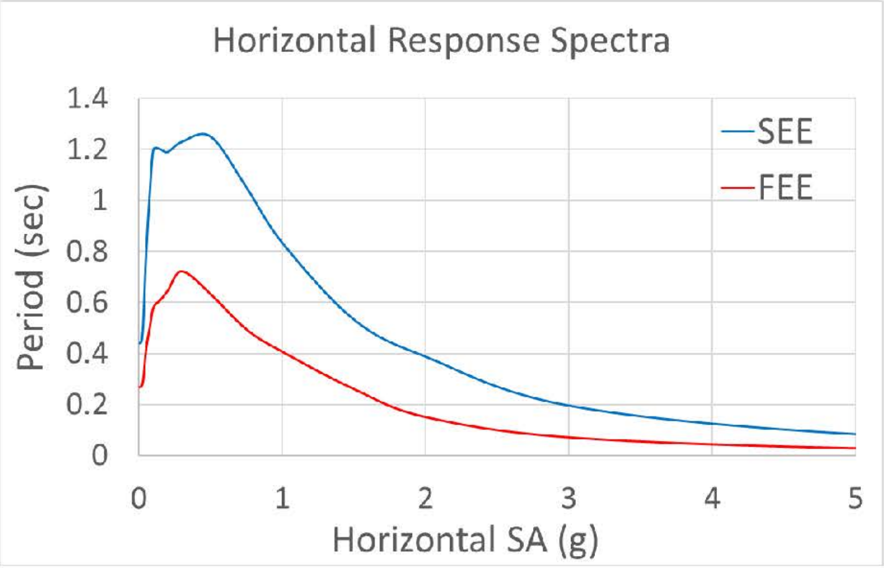
- Recovery Level Bridge
  - FEE (Functional Evaluation Earthquake)
    - Ductility at column to shaft = 2.0
    - Minimal Damage, open to traffic immediately
  - SEE (Safety Evaluation Earthquake)
    - Ductility at column to shaft = 3.5
    - Moderate Damage, extensive cracking, open to reduced traffic within 3 months

Design Level (1)	Ground Motion Amplitude Probability of Exceedance (PE)	Return Period (years)
FEE	30% PE in 75 years	210
SEE	7% PE in 75 years	1033

Seismic Response

- Displacement Ductility Demand Limits
- P-Δ was a driver of design (avoid NLTHA – time constraints)
- Balanced Stiffness and Balanced Frame Geometry
- Landslide
  - Flexible Pier helps with above
  - Need Robust Piers to restrain

	Transverse Fundamental Periods (sec)	Longitudinal Fundamental Period (sec)
Frame 1	2.65	3.00
Frame 2	3.95	3.98
Frame 3	3.14	2.58
Frame 4	2.97	3.02



Balanced Stiffness

- Frame 2 largest mass
- Frame 4 smallest mass
- Unbalanced stiffness mainly due to soil strata and landslide

Balanced Stiffness

- Fixed: superstructure mass, spans, shaft cutoff elevations, in-water pier constraints
- Adjustable: shaft stiffness, casing thickness, column silo configuration

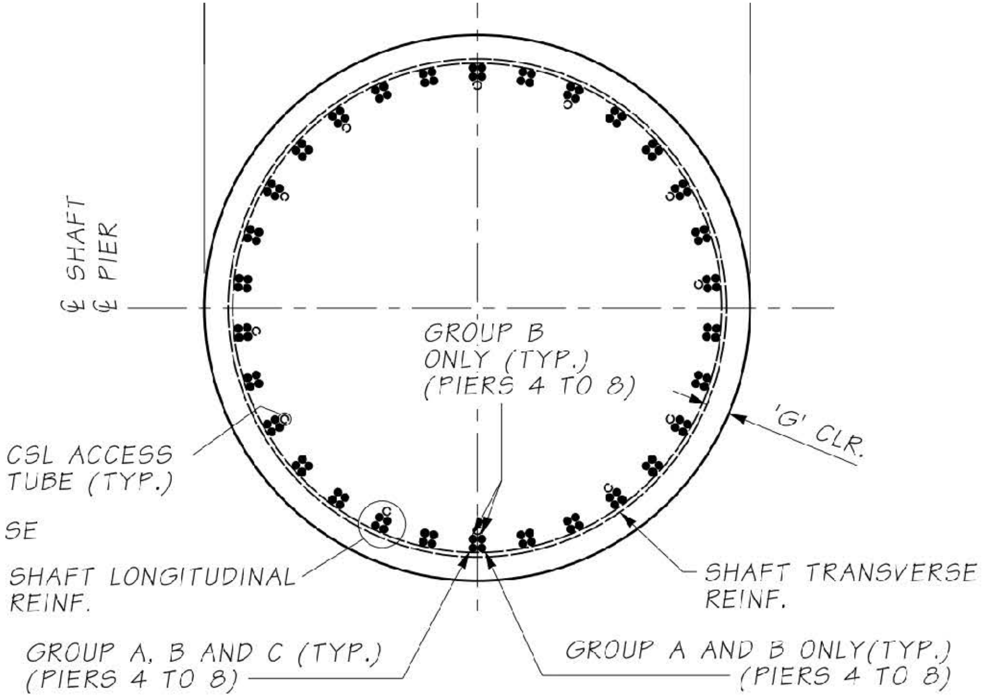
→ Foundation flexibility became the primary tuning mechanism

Foundation - Shafts

- 3-12 ft diameter drilled shafts
- Allows for 2D minimum spacing
  - Bottom Soffit & Column Width
- 1-1.75 in. thick steel casing
  - A709 Grade 50
  - Top of shaft to 5 ft into QPGL
- Casing extended to provide flexural resistance
- Casing thickness used in foundation stiffness tuning

Foundation - Reinforcement

- 2-bar bundles preferred
- A706 Grade 80 to reduce congestion
- f'_c = 5,000 psi
- 6 in. minimum clear spacing
- Group A/B/C longitudinal logic



Foundation - Constructability

- Pilot-hole excavation through hard layers
- Avoid dual reinforcement cages
- Detailing decisions influenced global behavior

Abutment Performance Objectives

- Utility protection at backwall, oversized openings
- Approach embankment protection
- ~1 in. transverse displacement target
- Non-fusible transverse shear key
- Iterative stiffness adjustment in RSA model

Soil-Structure Interaction Workflow

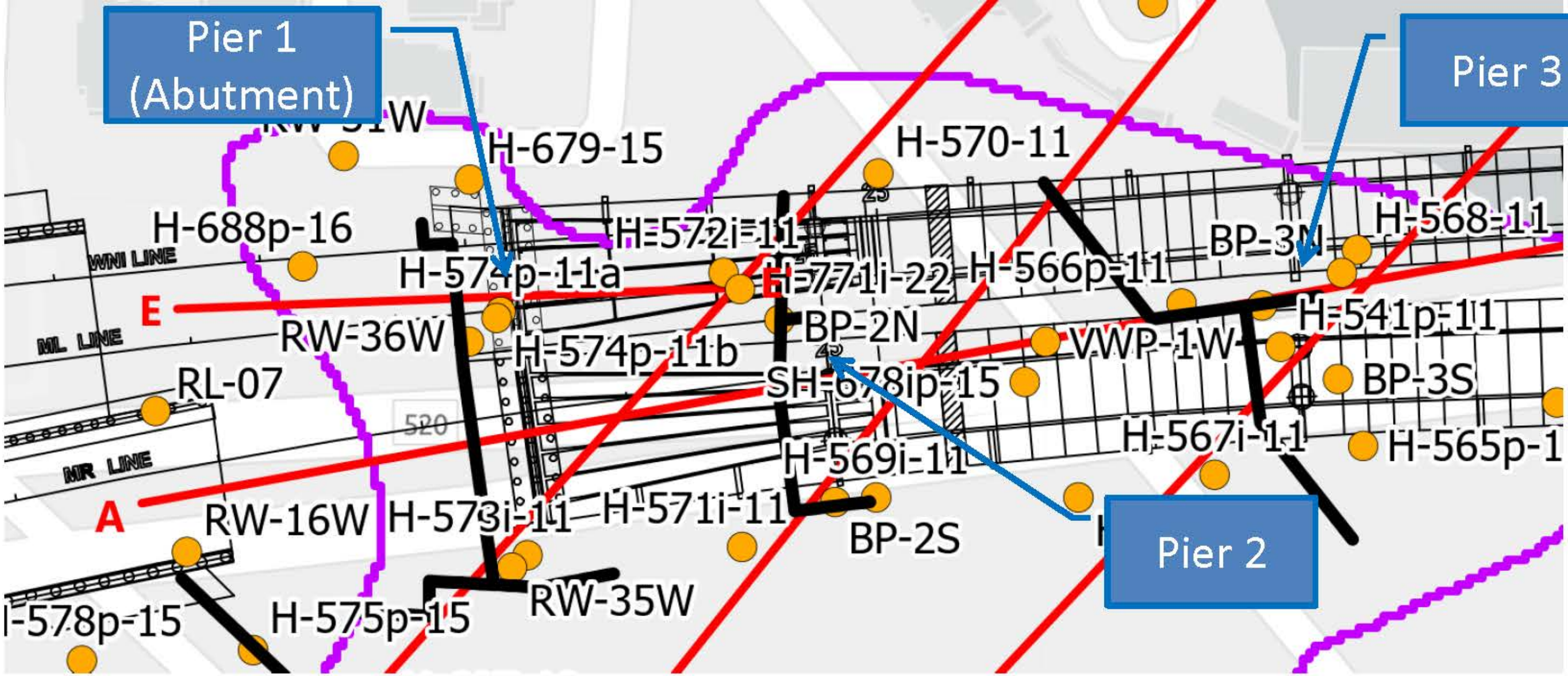
- SOFiSTiK / PGSuper → staging forces
- CSiBridge → global SEE/FEE RSA and pushover
- VBridge → global non-seismic, CIP box design
- VBent → bent-level analysis
- LPile / GROUP → SSI modeling
- Stiffness fed back to global model

Mp / Vp & Linear-Equivalent Strategy

- Plastic Mp & Vp from pushover
- Defined equivalent stiffness
- Avoid nonlinear iteration instability

Liquefaction & p-m Transitions

- Liquefied (seismic) and non-liquefied (non-seismic) soil models evaluated
- Reduced p-multipliers in group zones
  - Piers 2–11: for single row of drilled shafts
  - Abutments 1 & 12: per AASHTO (amended by WSDOT GDM)
- Transition from reduced Pm to 1.0 per geotechnical guidance
- Incorporated directly into global stiffness tuning iterations



Delmar Landslide

- Piers 1-3 sit within
  - Active Landslide
  - SEE induced (dynamic)
  - Smaller Scale "Service Landslides" (static)
- Preferred Performance Goal
  - Permanent Bridge Foundation
  - Landslide Protection Walls
  - Together mitigate the active slide

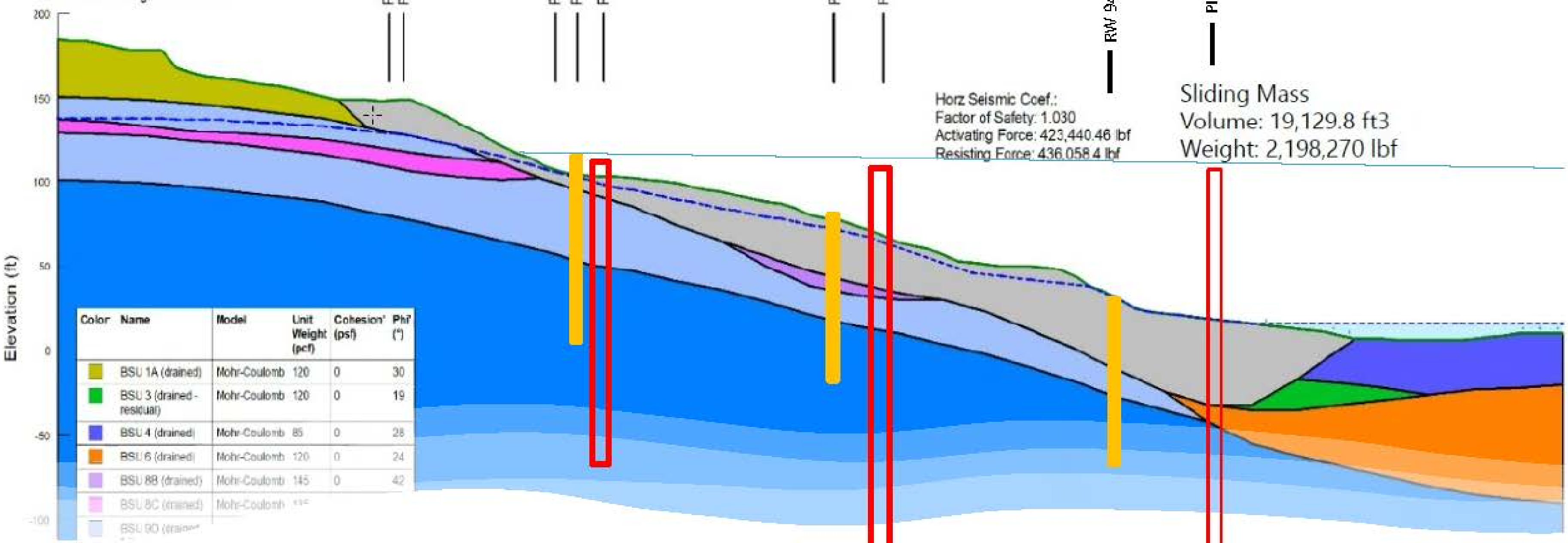
Delmar Landslide – Deformation Compatibility

1. Identify structural element critical slip surface
2. Soil Structure interaction using LPile P-Y Springs apply controlling load case and soil movement
   - LPile run in both directions, liquefied, and with/without landslide; seismic overstrength Mo/Vo combinations were included in landslide evaluation
3. Run with max soil movement that structure can adequately resist, then run smaller soil movements to obtain restraining force-resistance curve

Delmar Landslide – Deformation Compatibility

4. Repeat step 2 and 3 for other structural elements
5. Combine all structural elements to obtain Combined Structural Restraining Force-Resistance Curve for each slip surface
6. Verify and identify slope displacement compatibility where demand and resistance curves intersect
7. Landslide displacement was obtained to add to Δ_r increment for P–Δ check

Slope displacement vs Restraining Force at 90W-B & Abut 1 (SEE) @ Slip Surface B.2
B.2: Slip surface 30 ft (90W), 30 ft (Pier 1)
78.72 in DS (w/ 1.5 in Steel Casing & 1.3% Reinf.) @ 1.2D Spacing
8-39.36in DS (Pier 1) @ 2.9D Spacing
78.72 in (@ 1.2D spacing) + 3-36 in (@ 2.9D spacing)
90WB + PBBN Abut 1
Restraining Force (kips/ft)
550
500
450
400
350
300
250
200
150
100
50
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Soil Movement (in.)
1.25 in



Landslide Mitigation Walls

- Pier 1
  - RW 90W & RW 91W – 72” dia shafts with series of tiebacks
- Pier 2
  - RW 92W & RW 93W – 48” dia with 1” steel casing
- Pier 3
  - RW 94W– 48” dia with 1” steel casing

Key Lessons

- Foundation flexibility as tuning mechanism
- Recovery-Level demands displacement discipline
- Landslide design driven by slope displacement compatibility
- Early Geotech–Structural coordination critical
- Structured SSI workflow prevents modeling chaos
- Applicable to CA Recovery bridges

Thank You