Seismic Design Criteria of a Cable-Stayed Bridge- An Owner's Perspective

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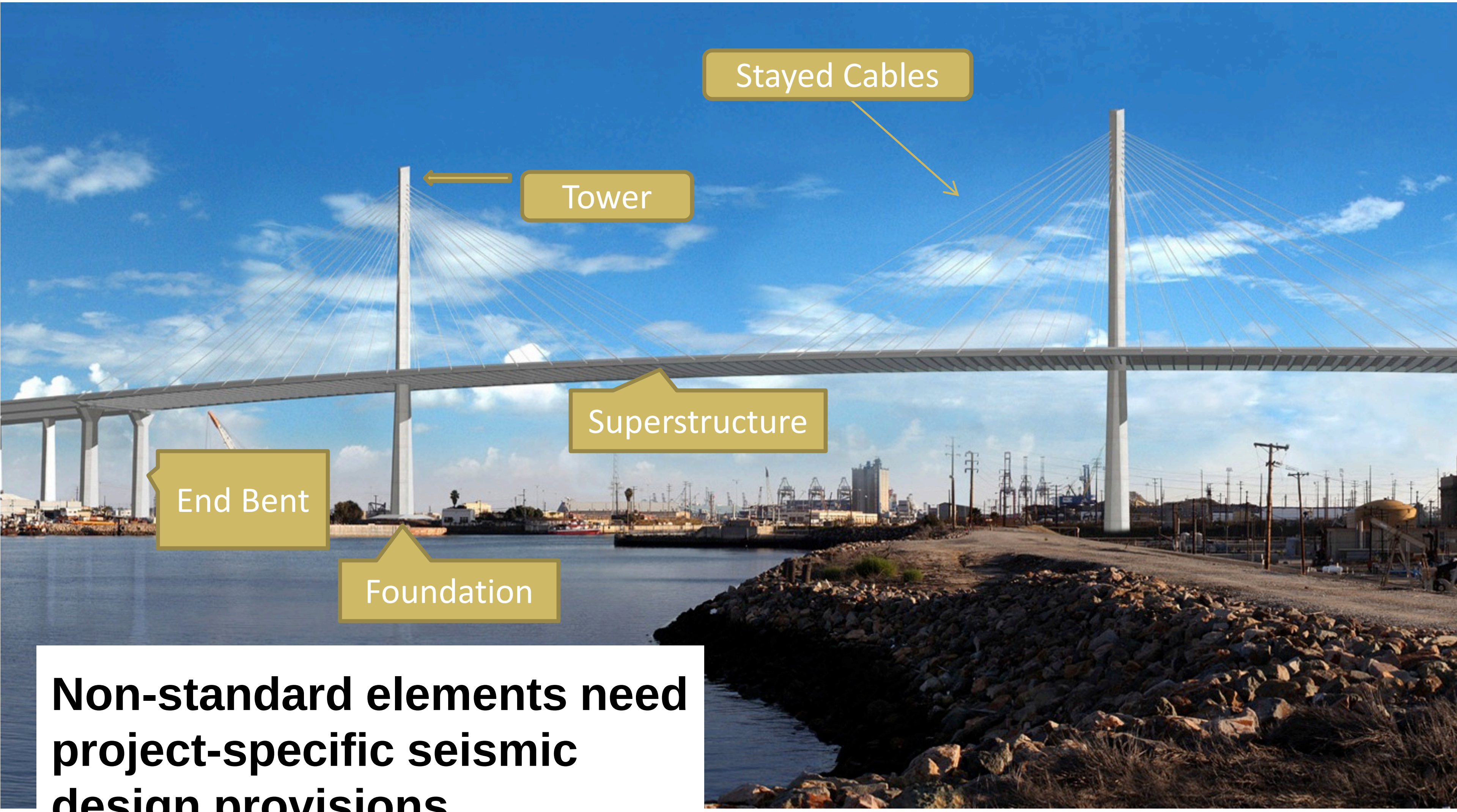
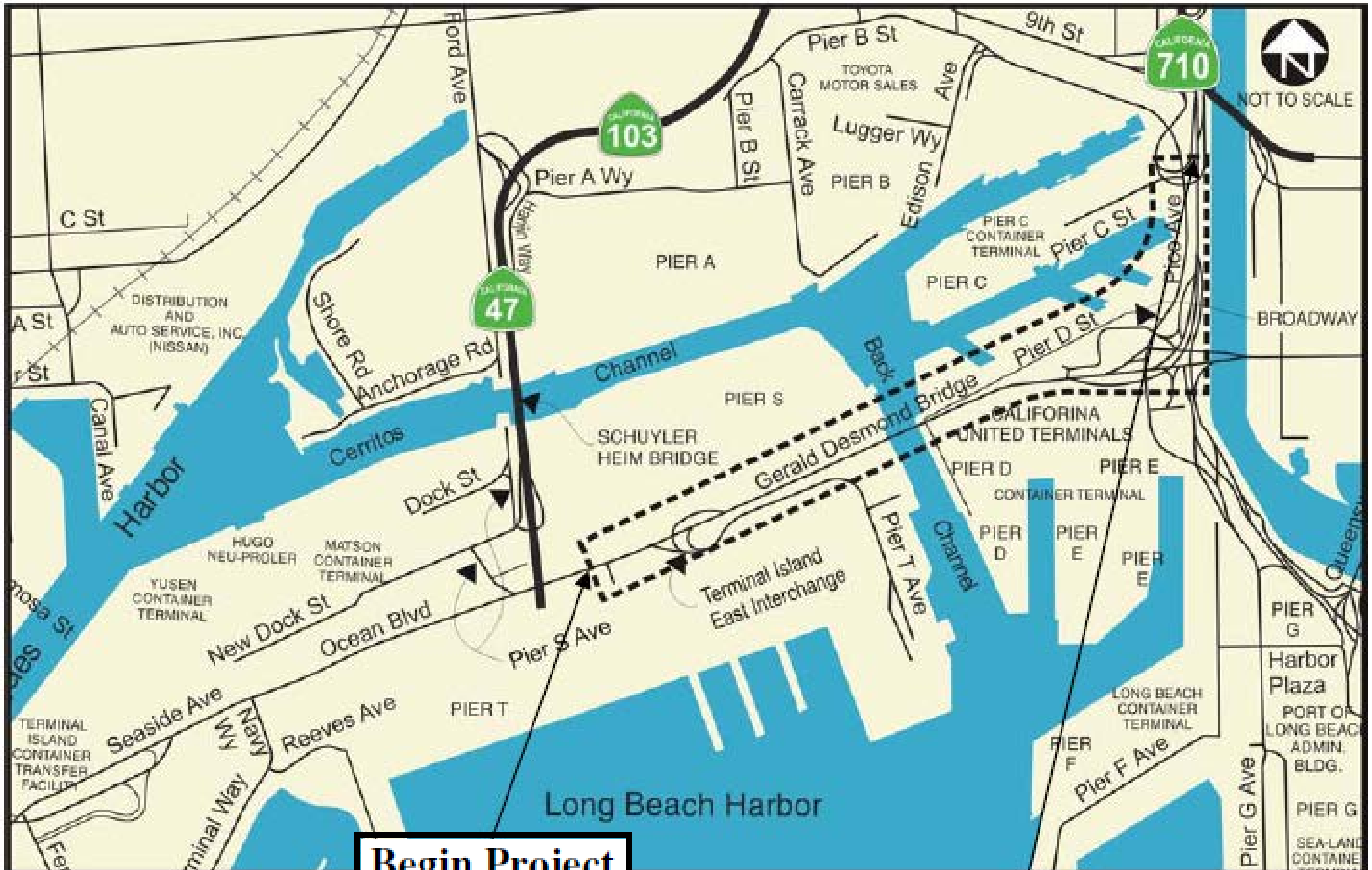
Cable-Stayed Bridge is an ordinary non-standard bridge Non-standard elements need project-specific seismic design provisions in addition to Caltrans Seismic Design Criteria



Non-standard elements need project-specific seismic design provisions

Gerald Desmond Bridge Replace

Port of Long Beach

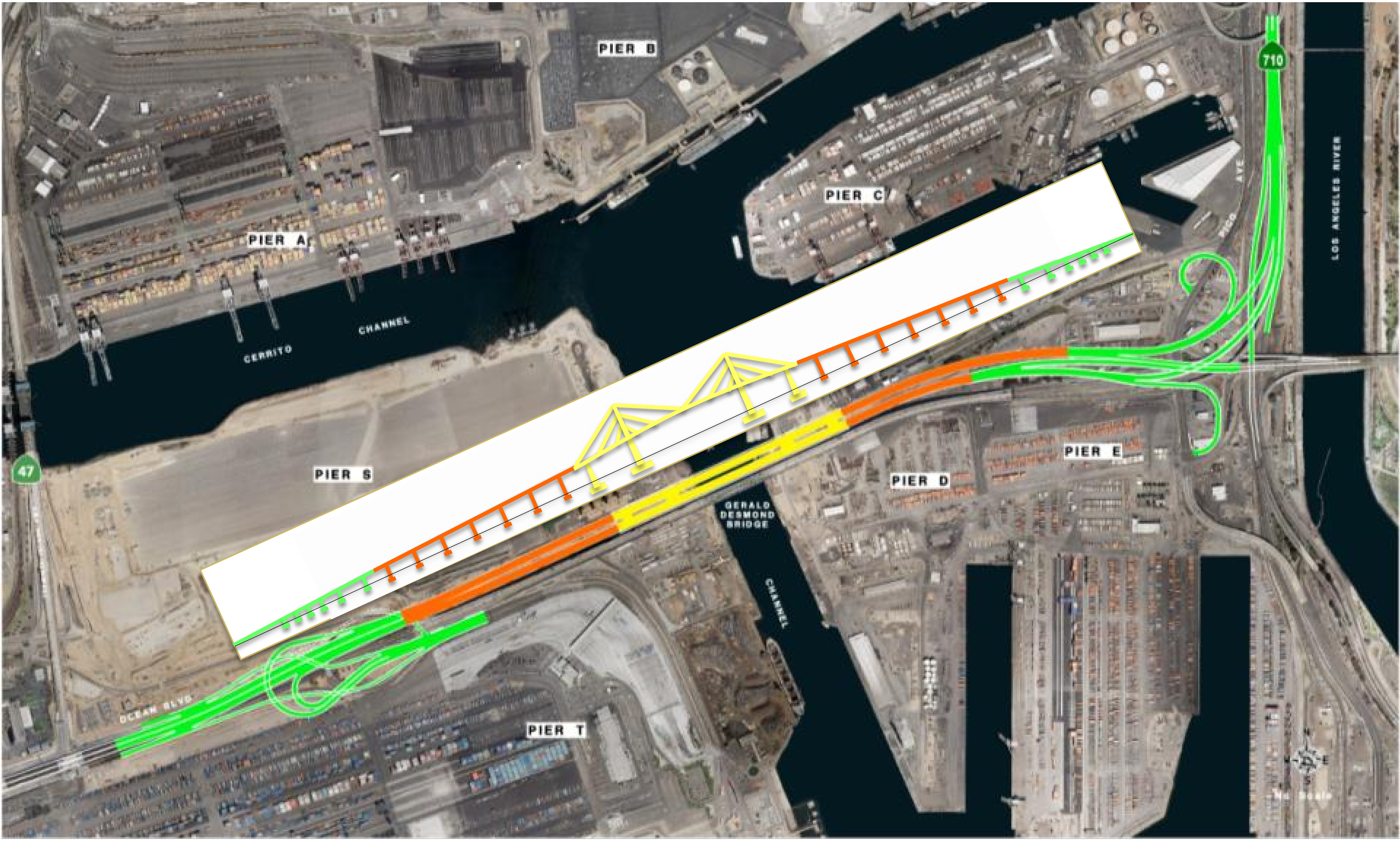


End Project
KP 9.4

Begin Project
KP 6.0

Construction of a new bridge north of existing old bridge with horseshoe ramps leading on/off the bridge

Preliminary Bridge Layout



Project Objective

•Signature span

•100-year life

•Enhance traffic volume and safety

•Enhance vessel passage and safety under the bridge

Meet Caltrans geometric and seismic standards and project-specific seismic design criteria

Gerald Desmond Bridge

- 2000’ cable-stayed bridge: 1000’ main span, 220’ vertical clearance
- Accommodate 3 lanes with 10’ shoulders in each direction

Main Span Cable-Stayed Bridge

- 2001-2010 Design-Bid-Build
  - Cable stayed- semi-harp two planes
  - 1000’ main span with 500’ back span each side
  - Mono towers- concrete sections
  - Steel girders with concrete deck
  - Pile foundation – large Ø piles
- 2010-present Design-Build contract
  - Prescribe technical requirements and design criteria in Contract
  - Bridge Owner at completion- Caltrans

Seismic Design Criteria- cable-stayed bridge

- Cable-stayed bridge is an ordinary non-standard bridge
  - Non-standard elements need project-specific seismic design provisions in addition Caltrans Seismic Design Criteria (CT-SDC)
- Foundations- piles, pile caps
- Tower and End Bent
- Cable System
- Superstructure

Seismic performance criteria

Bridge Owner’s Perspective:

- Responsibility for operation and maintenance
- Meet serviceability, maintainability, minimize life-cycle costs, life-safety

Two Tiers Seismic Performance design:

- Safety Evaluation Earthquake (SEE) –
  - ✓1000 years return period; non-collapse and repairable damage
- Functional Evaluation Earthquake (FEE) –
  - ✓100 years return period; bridge should be operational after the event (post-FEE), only cosmetic damage

Seismic performance criteria

FEE

- All structure elements- No damage
- Bearings- no damage
- Expansion joints- Minimal damage

Bridge Owner’s and Users Perspective:

- Bridge needs to be serviceable after FEE event
  - Full live loads on the bridge
  - All other service loads
- Any minor repairs (joints, barriers, fuses) not to impose full closure anytime nor lane closures during daytime hours
- Operations and Maintenance Manual to include special procedures after FEE event

Seismic performance criteria

SEE

- Foundations- piles: minimal damage
- pile caps
- Tower: minimal damage, permanent offset 6-in
- Shear links: significant damage
- Cables systems: no damage
- Superstructure: minimal damage
- Bearings, shear keys: Moderate damage
- Foundation permanent offset: repairable

Seismic performance criteria

Prescribe damage allowance, strain limits, capacity protection and reserve per Caltrans SDC

- No damage: nominal capacity per AASHTO LRFD, full serviceability w/o repair
- Minimal damage: minor inelastic response, narrow cracking in concrete
- Moderate damage: inelastic response, concrete cracking/cover spalling, rebar yielding, structural steel yielding
- Significant damage: major concrete spalling & deformation in minor components, require closure for repair. Partial or complete replacement of secondary elements (non gravity load system) may be required

Performance Level

Stay cables- minimum tension of 10% of dead load

Joints and Bearings- prevent collapse at SEE

	Allowable Concrete Strains @ SEE	**Allowable Concrete Strains @ FEE**
Towers & End Bents	0.004 $\leq$ 0.4 ultimate strains	0.003
Piles	0.004 $\leq$ 0.4 ultimate strains	0.003
All Other Elements	0.015 $\leq$ 0.75 ultimate strains	0.004
	Allowable Reinforcement Strains @ SEE	**Allowable Reinforcement Strains @ FEE**
Towers & End Bents	0.015	AASHTO LRFD
Tower/End Bt (Lateral Reinf)	0.05	AASHTO LRFD
Piles	0.015	AASHTO LRFD
All Other Elements	0.06	0.015

Seismic Demand Analysis

- Nonlinear dynamic time-history analysis
- Include main span and one approach bridge frame on each end
- Geometrically nonlinear DL and seismic analysis- account for geometric nonlinear stiffness of cable elements
- Non-linear boundary conditions
- Geometric nonlinearity and inelastic behavior for energy dissipating devices
- Material nonlinearity- D/C > 1.5
- Explicit foundation modeling- nonlinear inelastic soil-pile interaction effects

Tower Design Alternatives

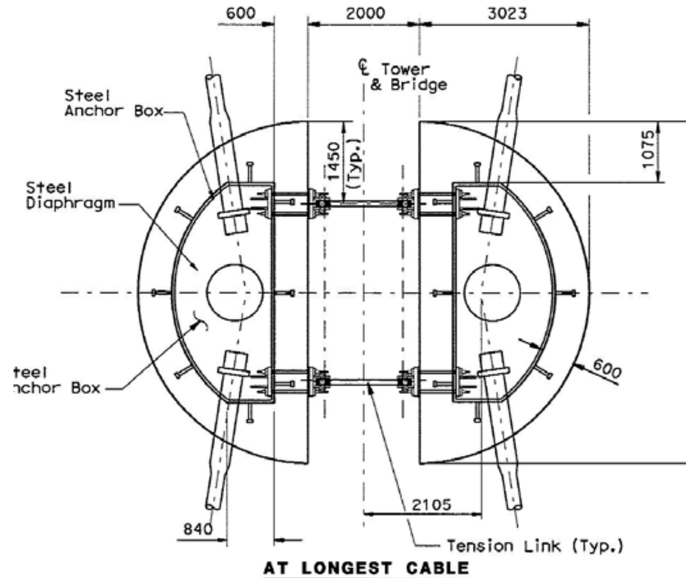
Tower Design- flexibility allowed in the design criteria:
Steel towers, Tower with Shear Links, viscous dampers
Steel Towers- prescribed strain limits

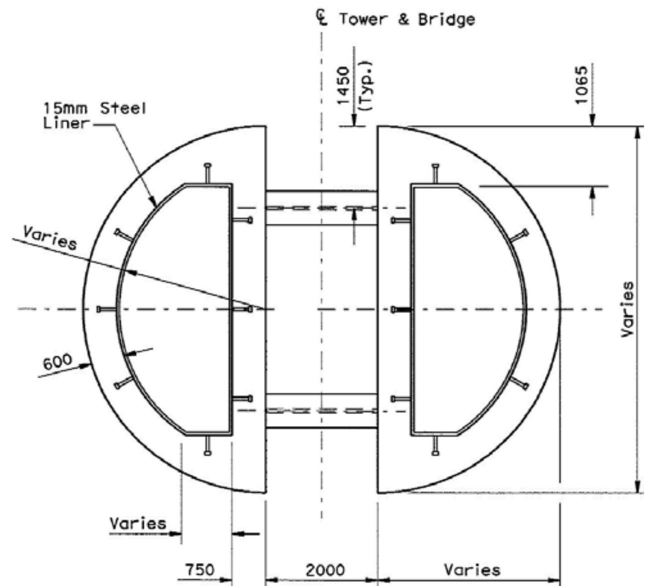
Steel Shear Links- preliminary design. Need full-scale prototype laboratory cyclic testing to validate the performance

Rotation Demands	SEE	FEE
Shear Links	0.1 radians	0.03 radians

Prescribe cyclic load testing protocol

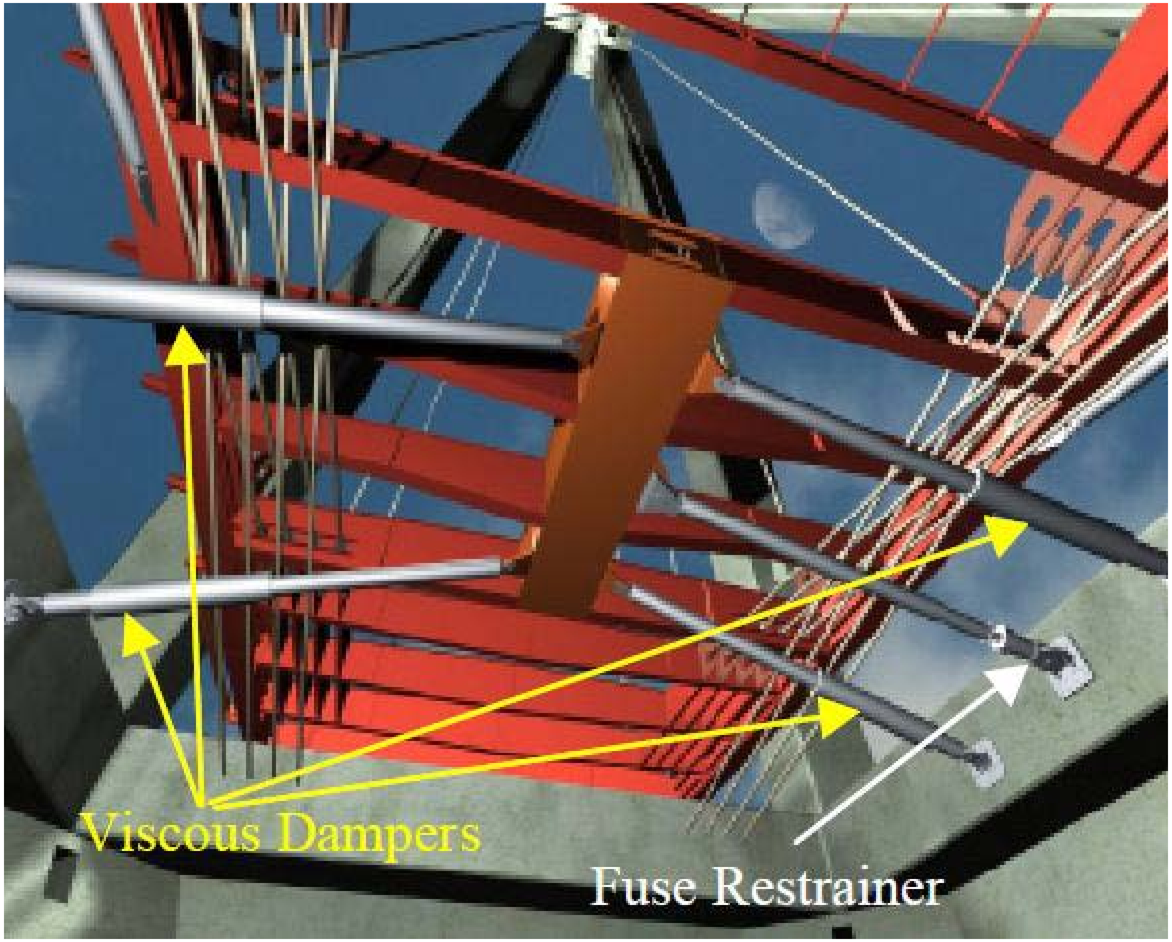
Steel Shear Link Alternative





Details by HNTB/Parsons JV

Viscous Dampers Alternatives



Rion Antririon Bridge, Greece

Viscous Dampers Alternatives

Prior applications in California

- SFOBB West Spans- Suspension Bridge (San Francisco)
- Vincent-Thomas Bridge- Suspension Bridge (San Pedro)
- Richmond-San Rafael Bridge- Steel Truss Bridge
- experience: sizeable percentage of dampers leaked within first 3 years-
  - ✓ Issues: fluids leaking and draining from dampers

Viscous Dampers

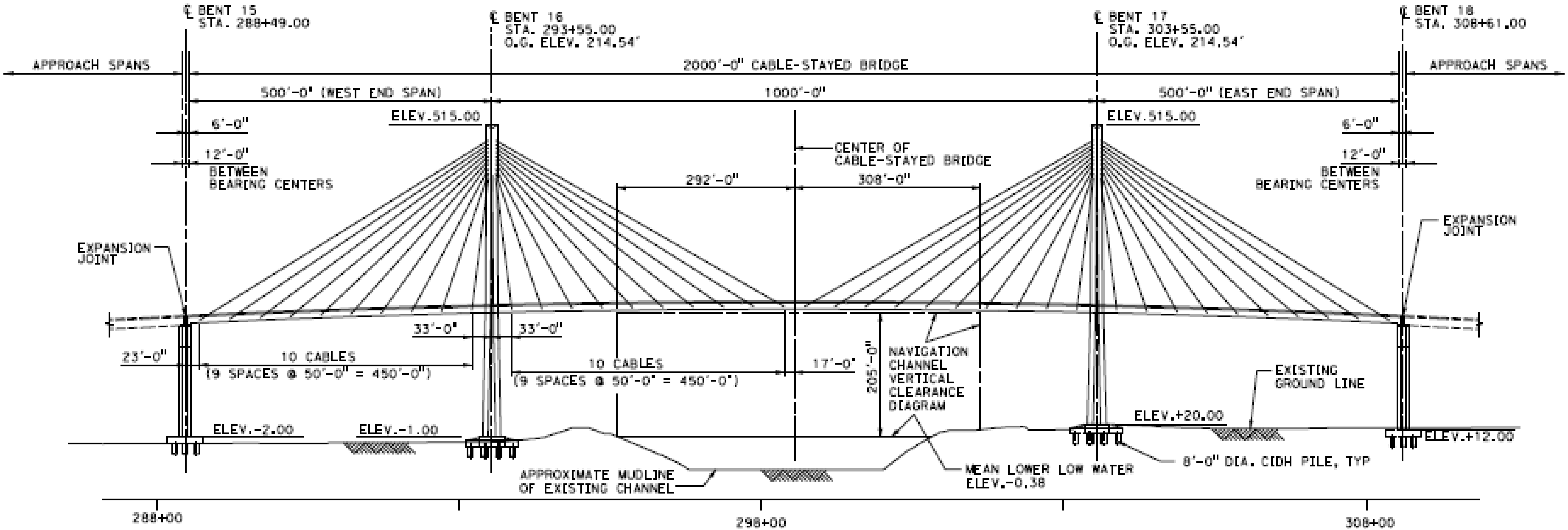
- Damper leakage- seals worn due to excessive daily piston movement from ambient, transient loads/vibrations
- Prescribe criteria:
- Viscous damper to be locked by a fuse (internal or external)
- Damper piston prevented from movement in non-seismic load combinations
- Fuse to be broken and damper to be activated in sizeable earthquake motions
- Testing protocol per AASHTO Guide Specs for Seismic Isolation Design
- Minimum 10 year warranty

Gerald Desmond Bridge
Replacement Project

Caltrans • Metro • Port of Long Beach • US Department of Transportation

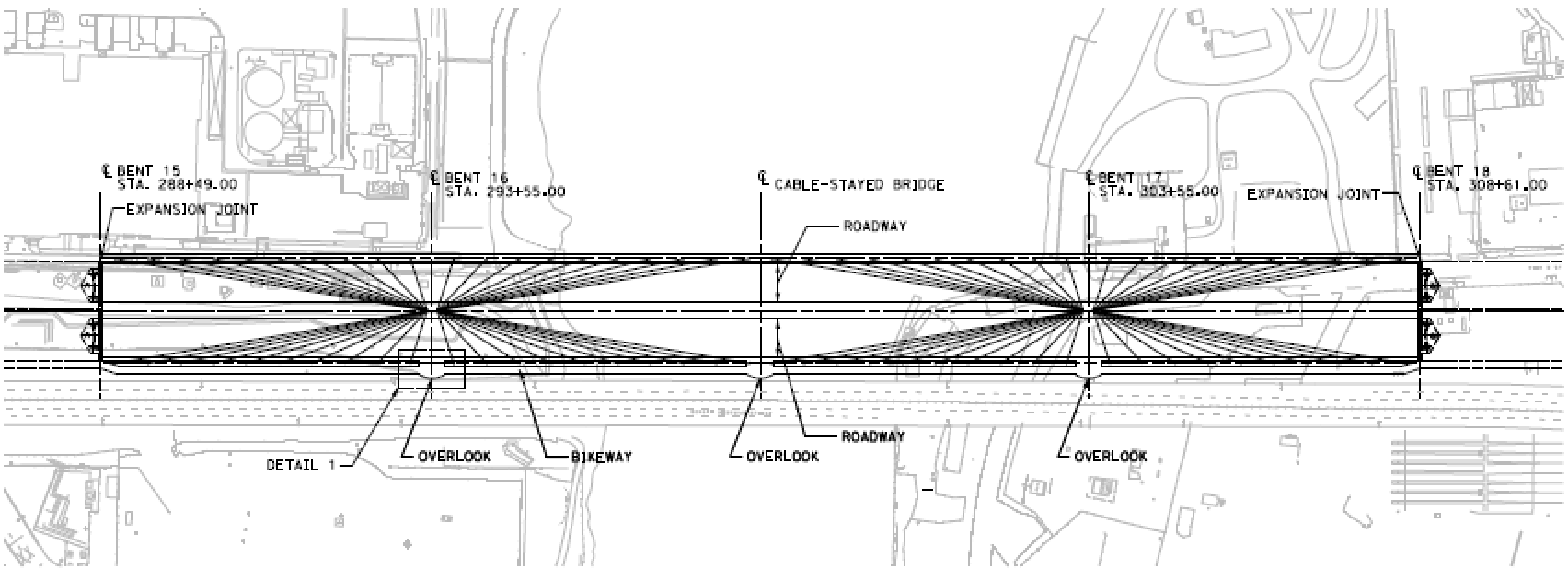
Design-Build Procurement

~$650 million design-build contract awarded to Shimmick, FCC, and Impregilo (SFI)- July 2012
Design Engineer: ARUP



ELEVATION

SCALE: 1" = 100'

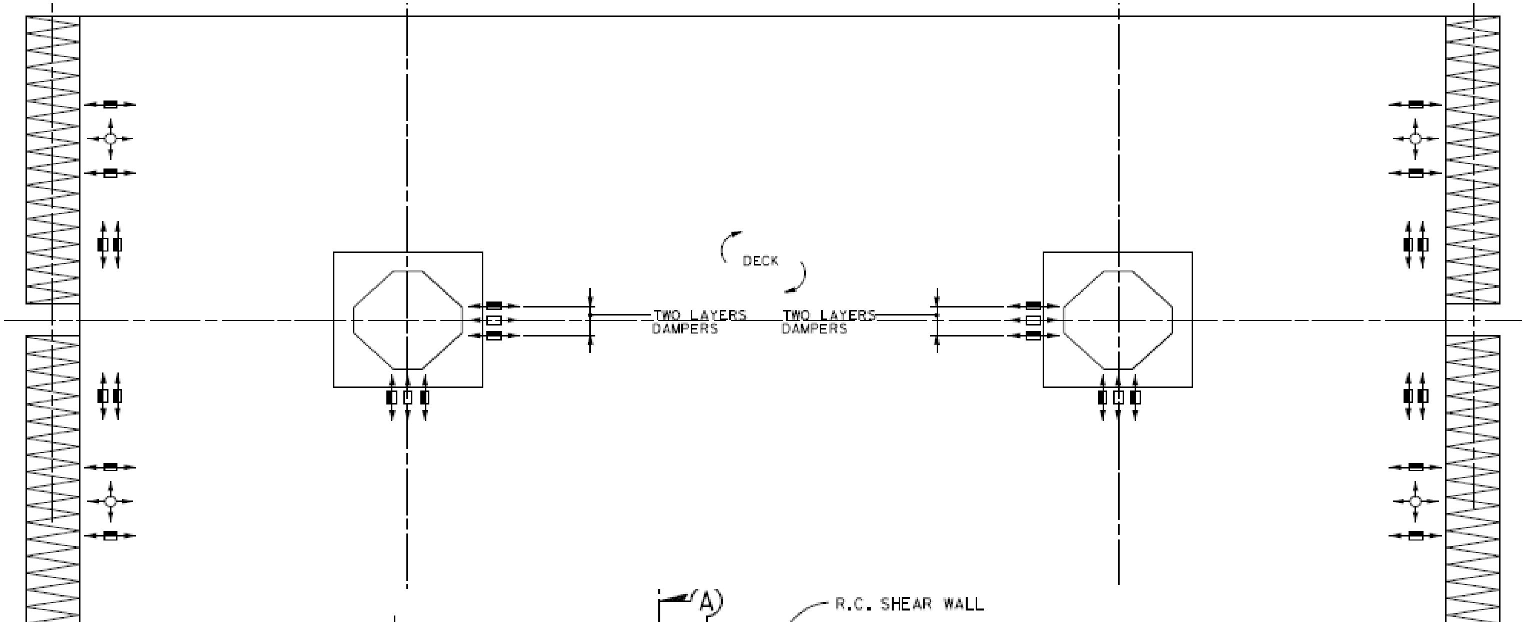


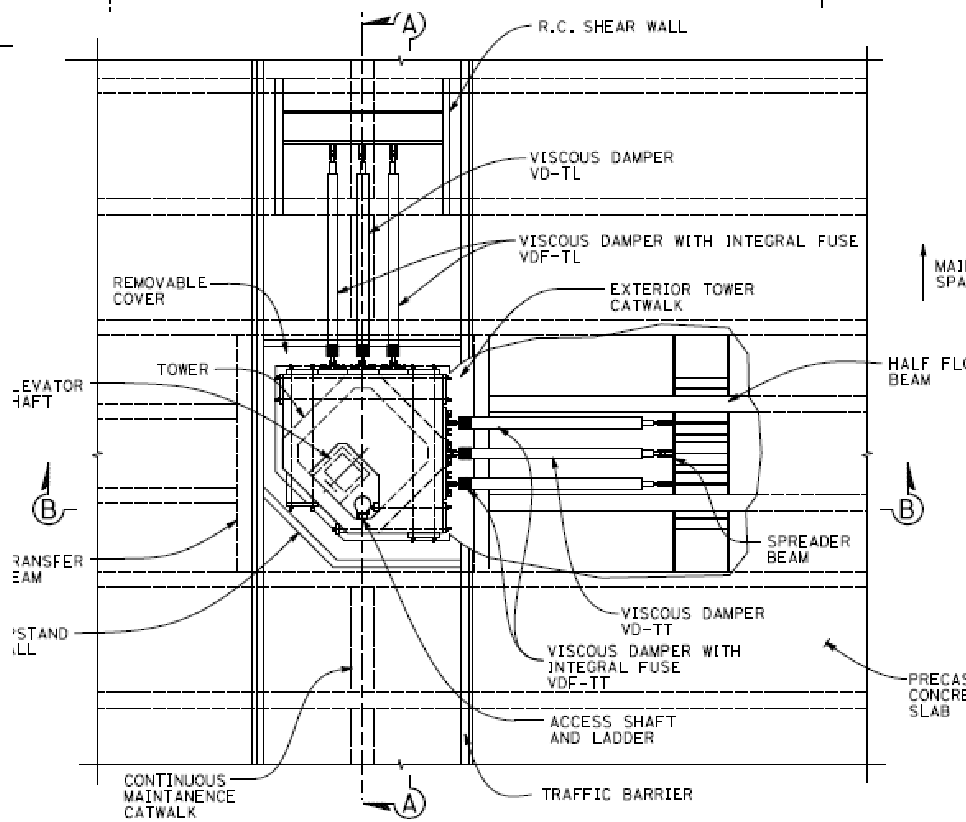
PLAN

SCALE: 1" = 100'

Cable-Stayed Bridge Design

- Tower- mono leg hollow section
  - Longitudinal and transverse viscous dampers with internal fuses
  - Tower section remain essentially elastic in FEE and SEE events
- End Bents- twin leg hollow section
  - Longitudinal and transverse viscous dampers with internal fuses


DECK
TWO LAYERS DAMPERS
TWO LAYERS DAMPERS


A
R.C. SHEAR WALL
VISCOUS DAMPER VD-TL
VISCOUS DAMPER WITH INTEGRAL FUSE VDF-TL
MAIN SPAN
REMOVABLE COVER
EXTERIOR TOWER CATWALK
TOWER
LEVATOR HAFT
HALF FLO BEAM
B
B
RANSFER EAM
SPREADER BEAM
STAND LL
VISCOUS DAMPER VD-TT
VISCOUS DAMPER WITH INTEGRAL FUSE VDF-TT
PRECAS CONCRE SLAB
ACCESS SHAFT AND LADDER
CONTINUOUS MAINTANENCE CATWALK
TRAFFIC BARRIER
A

Design Status:

Type Selection: February, 2013

Foundation System- > 65%

Tower, Cables, Anchorages, Dampers- 65%

Gerald Desmond Bridge
Replacement Project

Caltrans • Metro • Port of Long Beach • US Department of Transportation

Thank You !

Owner's Design Review Consultant: HNTB/Parsons JV (original and preliminary designer)

Owner's PM/CM: Parsons Brinckerhoff