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.
Gerald Desmond Bridge Replace
Port of Long Beach

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

<table>
<thead>
<tr>
<th></th>
<th>Allowable Concrete Strains @ SEE</th>
<th>Allowable Concrete Strains @ FEE</th>
</tr>
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<tbody>
<tr>
<td>Towers &amp; End Bents</td>
<td>0.004 ≤ 0.4 ultimate strains</td>
<td>0.003</td>
</tr>
<tr>
<td>Piles</td>
<td>0.004 ≤ 0.4 ultimate strains</td>
<td>0.003</td>
</tr>
<tr>
<td>All Other Elements</td>
<td>0.015 ≤ 0.75 ultimate strains</td>
<td>0.004</td>
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</tbody>
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<th>Allowable Reinforcement Strains @ SEE</th>
<th>Allowable Reinforcement Strains @ FEE</th>
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<tr>
<td>Towers &amp; End Bents</td>
<td>0.015</td>
<td>AASHTO LRFD</td>
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<tr>
<td>Tower/End Bt</td>
<td>0.05</td>
<td>AASHTO LRFD</td>
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<tr>
<td>(Lateral Reinf)</td>
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<tr>
<td>Piles</td>
<td>0.015</td>
<td>AASHTO LRFD</td>
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<tr>
<td>All Other Elements</td>
<td>0.06</td>
<td>0.015</td>
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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

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<th>SEE</th>
<th>FEE</th>
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<tr>
<td>Shear Links</td>
<td>0.1 radians</td>
<td>0.03 radians</td>
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</table>

Prescribe cyclic load testing protocol
Steel Shear Link Alternative

Details by HNTB/Parsons JV
Viscous Dampers Alternatives

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

**ELEVATION**

Scale: 1" = 100'

**PLAN**

Scale: 1" = 100'

Detail 1:
- Overlook
- Bikeway
- Roadway

Existing Channel Line

Mean Lower Low Water
Elev. -0.38

Navigation Channel Vertical Clearance Diagram

8' 0" Dia. CDH Pile, Typ
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
Design Status:
Type Selection: February, 2013
Foundation System - > 65%
Tower, Cables, Anchorages, Dampers - 65%
Owner’s Design Review Consultant: HNTB/Parsons JV (original and preliminary designer)
Owner’s PM/CM: Parsons Brinckerhoff