Accelerated Bridge Construction in Pacific Northwest Seismic Regions

Outlines:

- Accelerated Bridge Construction in Washington
- Fully Precast Bridges – HFL
- UHPC Pier Connections
- Superelastic Materials - IBRD
- Prestressed Columns with Self Centering Capability

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WSDOT - Bridge & Structures Office
Accelerated Bridge Construction & Seismic Challenges

**ABC**
- Easy to assemble.
- Generous tolerances.
- Fast in the field.
- Common materials.

**Seismic**
- Continuous load path.
- Robust.
- Avoid eccentricities.
- Energy Dissipation.
- Protect brittle elements.
- No stress concentrations.

**PBES bent connections**

**So what is the problem?**
Requirements for ABC and seismic often conflict. Need approaches that solve both problems together.
Examples of WSDOT ABC Projects

Hood Canal Approach Bridge Construction
ABC - Bridge Lateral Slide: Night Closure

7 pm Saturday September 14th

Bridge Move Summary:
1. Temporary Span out (25 min.)
2. Permanent Span in (45 min.)
3. Deck Lowering (30 min.)

http://wwwi.wsdot.wa.gov/eesc/bridge/ABC/

2 pm Sunday September 15th
Existing bridges constructed via this method have shown poor performance from the welded bars.

**Proposed Solution:** Eliminate the welds and use UHPC to create the longitudinal joint.

**SCOPE:** Develop a new, inexpensive UHPC mix using local materials, test its structural performance, and specify a joint width.
Bridge Substructure & Seismic Design Requirements

Connections need to be:
- Constructible
- Seismic Resilient – Emulative
- Long term Performance & Longevity
Seismic Design Specifications

- 2014 Seismic Hazard Maps and Site Coefficients
- FEE and SEE Two level Seismic Design
- Grade 80 A706 Rebar
- Member socket connection at base
- Large, bars at precast cap connection
- Two-stage cap
- Upper stage CIP
- Girders integral with combined lower and upper stages of cap
Precast Bridge System in High Seismic Regions - HFL
Column-to-Cap Connection

Connection Tests (42% Scale)

Moment vs. Drift

Same response for precast and CIP
## Column-to-Spread Footing and Shaft Connection Tests

### Column-Shaft Tie Reinforcement

<table>
<thead>
<tr>
<th></th>
<th>DS-1</th>
<th>DS-2</th>
<th>DS-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Diameter</td>
<td>20 in.</td>
<td>20 in.</td>
<td>20 in.</td>
</tr>
<tr>
<td>Column Reinforcement Ratio</td>
<td>1.0 %</td>
<td>1.0 %</td>
<td>1.6 %</td>
</tr>
<tr>
<td>Shaft Diameter</td>
<td>30 in.</td>
<td>30 in.</td>
<td>26 in.</td>
</tr>
<tr>
<td>Lateral Reinforcement Efficiency Factor ($k$)</td>
<td>0.75</td>
<td>0.375</td>
<td>1.30</td>
</tr>
<tr>
<td>Top 1 ft.</td>
<td>0.50</td>
<td>0.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Upper Half</td>
<td>0.50</td>
<td>0.25</td>
<td>1.00</td>
</tr>
<tr>
<td>Lower Half</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure</td>
<td>Column</td>
<td>Shaft</td>
<td>Column</td>
</tr>
</tbody>
</table>

Spread Footing Connection

- Column crushed at: 3.5 * ($1.25DL + 1.75SL$)
- No damage to footing,
- No sign of punching failure

Socket Connection – Internal Forces
Precast Bridge System in High Seismic Regions - HFL

- PCI Journals
- Webinars
- Showcase

Precast Bent Cap Placement
- Two Erection Cranes
- Segment Weight: (120 & 165 kips)
- 16 Duct Connection per Segment
- CIP Closure
Examples of WSDOT ABC Projects

Precast Bent: Grouted Duct Connection
SR 202 / SR 520
1 1/2 Hours +/-
Bent Cap Erection

SR 520 Floating Bridge & Landings
Precast Crossbeam – Pier 36

EB Nalley Valley Project Precast Bents

Precast Column-Foundation Connection
HFL Precast Column Concept For City of Redmond 36th St. Bridge Project

Contractor Initiated Precast Column Idea – Saved One Month
Concrete filled Steel Tubes

Ductility

Deep Foundation

Lateral EQ Load
Two-level performance criteria are required for design of Essential and Critical bridges.

- **FEE**: 30% probability of exceedance in 75 years – 210 yrs Return Period
- **SEE**: 7% probability of exceedance in 75 years – 975 yrs Return Period

Bridges are considered as Critical, Essential, or Normal for their operational classification as described below.

- **Critical Bridges** - are expected to **provide immediate access** to emergency and similar life-safety facilities after an earthquake.

- **Essential Bridges** - serve as vital links for rebuilding damaged areas and **provide access to the public shortly after** an earthquake. All bridges within the seismic lifeline are considered Essential bridges.

- **Normal Bridges** - All bridges away from Lifeline not designated as either Critical or Essential are designated as Normal.
# Seismic Design Performance Criteria

- **Normal Bridges:** One Level
- **Essential Bridges:** Two Level
- **Critical Bridges:** Two Level

<table>
<thead>
<tr>
<th>Seismic Critical Member</th>
<th>Displacement Ductility Demand Limits</th>
<th>Seismic Hazard Evaluation Level</th>
<th>Expected Post EQ Damage State</th>
<th>Expected Post EQ Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal Bridges</td>
<td>Essential Bridges</td>
<td>Critical Bridges</td>
<td></td>
</tr>
<tr>
<td>Pier Wall in Weak Direction</td>
<td>SEE</td>
<td>FEE</td>
<td>SEE</td>
<td>FEE</td>
</tr>
<tr>
<td>Pier Wall in Strong Direction</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Single Column Bent</td>
<td>SEE</td>
<td>FEE</td>
<td>SEE</td>
<td>FEE</td>
</tr>
<tr>
<td>Multiple Column Bent</td>
<td>5.0</td>
<td>2.5</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Pile Column with Plastic Hinge at Top of Column</td>
<td>6.0</td>
<td>3.5</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Pile Column with Plastic Hinge Below Ground</td>
<td>5.0</td>
<td>3.5</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Superstructure</td>
<td>4.0</td>
<td>2.5</td>
<td>1.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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**NCHRP: Performance Based Seismic Design**
Seismic isolation bearings are designed per LRFD, SGS, Isolation GS, and BDM.

- Expansion joints accommodate seismic movements required for isolation bearings to function properly.
- Adequate clearance at abutments for seismic displacement.
- Combinations of isolation bearings and conventional bridge column fixity are not allowed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Trans &amp; Longit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic Total Design Displacement range (TDD)</td>
<td>6 to 24 inches</td>
</tr>
<tr>
<td>Isolated Structure Effective Period (T)</td>
<td>2 to 3 seconds</td>
</tr>
</tbody>
</table>
Innovative Bridge Design – Super Elastic Materials

Diagram:
- **Stress-Strain Curve:**
  - **A:** Unstressed austenite
  - **B:** Stress plateau
  - **C:** Forward transformation
  - **D:** Stress transformed to martensite
  - **E:** Reverse transformation
  - **F:** Zero residual strain

- **Graph:**
  - **X-axis:** Strain (%)
  - **Y-axis:** Tensile Stress (MPa)

- **Images:**
  - Conventional Concrete
  - Shapeable Concrete

- **Stress vs. Strain Diagram:**
  - Load and Unload cycle showing superelastic behavior.
Innovative Super Elastic Materials - SMA

- Superelastic Nickel-Titanium Shape Memory Alloy (SMA) Bars
  - Reduce residual displacements

- Challenges with including SMA
  - Cost
  - Schedule – 6 month delivery, not including process to head bar for mechanical splice
  - Mechanical splice required in hinge region
WSDOT Bridge Column Test - UNR

- Three - 0.4 Scale Columns
  - 2 Incorporating SMA and ECC
  - 1 Conventional RC
- 62 in clear height
- 18 in x 18 in cross-section
- Cyclic loading

Damage at End of Testing

SR99-RC (8% Drift)  SR99-LSE (12% Drift)  SR99-SSE (10% Drift)
SR 99 South Tunnel off Ramp Access

- Bridge Completed in 2018
- Open to traffic 2/2019
Seismic Resiliency – Self Centering Precast Columns

PT, unbonded in the tree height of the column. Remains elastic.

Bonded rebar yields cyclically, dissipates energy.

Column rocks as a rigid body:
- no curvature
- no strain
- no cracking
Local high stress at Interface.

Central grouted duct
Rebar duct
Reduced damage section
Bonded strand
Locally debonded mild reinforcing
Fiber reinforced grout pad
Confining tube
Unbonded strand
Discontinuous rebar
Seismic Resiliency – Self Centering Precast Columns

Testbed with Self-Centering Columns

- Design method:
  - Mild reinforcement reduced
  - Prestressing force from a central unbonded tendon
  - Same envelop Q-δ
  - Peak displacements within 10% of RC column
  - Residual displacements less than 20% of RC column

Prestressed Columns with Self Centering Capability for Seismic Resiliency

First Application of Self-centering prestressed bents: Elwha River Bridge Replacement

Bending
- Tension cracks and compression crushing

During Earthquake
- Strands elongate due to joint opening.

After Earthquake
- Force in strands rights the column.

Minimal strength degradation & cross-over displacements

Conventional

Pretensioned, Rocking
Seismic Resiliency – UHPC for Column PH Regions
Proposed Research: FIU-UHPC Connection Tests

UHPC + Shape Memory Alloy in Plastic Hinging zone and ECC
2019-21 Biennium Bridge Research Projects:

- Performance of Steel Jacket Retrofitted Reinforced Concrete Bridge Columns in Cascadia Subduction Zone Earthquakes
- Effects of Cascadia Subduction Zone M9 Earthquakes on Bridges in Washington State

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