Use of Precast Members For Accelerated Bridge Construction in Washington State

Bijan Khaleghi
Concrete Specialist
Washington State Department of Transportation
Bridge and structures Office
Olympia, Washington
Precast Bridges

Advantages:
• Precasting Accelerates Bridge Construction
• Precasting Eliminates Concrete Forming, Casting and Curing in the Jobsite
• Precasting Improves Work zone Safety

Concerns:
• Seismic Design and Detailing Guidelines
• Monolithic Seismic Resistant Connections
• Construction Equipment and Cost
• Construction Tolerances
Seismic Design in Washington State

Major Faults in Puget Sound

- Everett
- Seattle
- Tacoma
- Olympia
## Recent Earthquakes

### Comparison of Seismic Events

<table>
<thead>
<tr>
<th></th>
<th>NISQUALLY</th>
<th>KOBE</th>
<th>NORTHRIDGE</th>
<th>LOMA PRIETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>6.8</td>
<td>6.9</td>
<td>6.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Peak Acceleration (a)</td>
<td>0.25</td>
<td>0.80</td>
<td>1.00</td>
<td>0.60</td>
</tr>
<tr>
<td>Depth of Rupture (km)</td>
<td>52.0</td>
<td>14.3</td>
<td>18.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Duration (sec.)</td>
<td>10</td>
<td>11</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Bridge Damage ($ x Millions)</td>
<td>$5</td>
<td>$6,700</td>
<td>$300</td>
<td>$1,500</td>
</tr>
</tbody>
</table>
Seismic Design

Fix Connection
Double-Curvature

Hinge Connection
Single-Curvature

EQ Force

Shape

Moment Diagram

Fixed

Pinned

Fixed

6th International Bridge Conference
SEISMIC DESIGN RESPONSE SPECTRA

ACCELERATION (g)

pile supported footing
Spread Footing foundation
shaft foundation

T = 2\pi\sqrt{\frac{m}{k}}

for SDOF undamped free vibration.

1
2
3
4

PERIOD (sec.)

SHAFT FOUNDATION
PILE FOUNDATION
SPREAD FOOTING
Key Factors in Seismic Design

- Precast Girder
- Expansion joint
- CIP Slab
- Joint-less Superstructure
- In-Span Hinge
- Backfill
- Elastomeric Bearing pad
- Seat width for seismic movement
- Girder stop to restrain transverse movement
- Ductile Connection
- Gap for seismic movement
- L-shape
- Abutment
- Pile-to-pile cap Connection
- Shaft
- Semi Integral End Pier
Seismic Design at Intermediate Piers
(C-I-P or Precast)

Response Spectrum Analysis

Seismic Elastic Forces

Plastic Hinging Forces

$$M_{\text{Design}} = M_E/R$$
Fixed Intermediate Diaphragm

- **CL Column and Diaphragm**
- **CIP Slab**
- **Precast Girder**
- **Extended Strands for M+ Connection**
- **Confinement Reinforcement**
  \[ \rho_s \geq 0.45 \left( \frac{A_s}{A_e} - 1 \right) \frac{f'_c}{f_{sh}} \]
  \[ \rho_s \geq 0.12 \frac{f'_c}{f_{sh}} \]
- **Column Connections**
  \[ V_n \leq 0.38bd \sqrt{f'_c} \]
- **Plastic Hinging**
  \[ M_p & V_p \]
- **Plastic Hinging**
  \[ M = M_p + V_p h \]
- **Construction Joint in Column**

C.G. of superstructure

6th International Bridge Conf.
Seismic Resistant Connections (Monolithic Connections)

2001 India Earthquake

Monolithic Connection, WA

2001 Nisqually Earthquake
Design for Continuity
Joint less Superstructure

Elevation

Kobe, Japan (1995)
Positive Moment Connection
Strand Anchor Detail

Pier Cap
CIP Diaphragm
Prestressed Girder
1’-6”
1”x 7”φ Anchor Plate
Bonded Strands
CL Girder
Strand Anchor or Chucks

Alternate 3

Alternate 1 or 2

CL Girder
Strand Anchor
Extended Strands
(Fixed intermediate Diaphragm)

\[ N_{PS} = 12 \left( M_C + V_C \times h - M_{SIDL} \right) \frac{N_C}{N_g} \times \frac{k}{0.9} \times A_{PS} \times f_{PS} \times xd \]

- \( M_C \) = Lesser elastic or plastic hinging moment of column, ft-kips
- \( M_{SIDL} \) = Moment due to traffic barriers and sidewalk, ft-kips
- \( V_C \) = Lesser of elastic or plastic hinging shear of column, kips
- \( h \) = Distance from top of column to centroid of superstructure, ft
- \( d \) = Distance from top of slab to centroid of extended strands, in
- \( N_C \) = Number of columns in the pier
- \( N_g \) = Number of prestressed girders in the pier
- \( A_{PS} \) = Area of each extended strands, in\(^2\)
- \( f_{PS} \) = Ultimate strength of prestressing strands, ksi
- \( k \) = Span coefficient (k=0.5 for \( L_1 = L_2 \), k = 0.67 for \( L_1 = 2L_2 \))
## Extended Strands for Positive Moment Connection (Fixed intermediate Diaphragms)

<table>
<thead>
<tr>
<th>Type of Girder</th>
<th>SE 8th I/C</th>
<th>Methow River</th>
<th>HPC Showcase</th>
<th>Bone River</th>
<th>Jenkins Creek</th>
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<tbody>
<tr>
<td>W58G 4</td>
<td>W83G 7</td>
<td>W74G 5</td>
<td>W74G 5</td>
<td>W74G 9</td>
<td></td>
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<tr>
<td>W58G 6</td>
<td>W83G 5</td>
<td>W74G 4</td>
<td>W74G 4</td>
<td>W74G 3.5</td>
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<tr>
<td>W58G 1</td>
<td>W83G 2</td>
<td>W74G 2</td>
<td>W74G 3</td>
<td>W74G 3</td>
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<td>W58G 9630</td>
<td>W83G 6250</td>
<td>W74G 4840</td>
<td>W74G 4920</td>
<td>W74G 3660</td>
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<tr>
<td>W58G 1067</td>
<td>W83G 887</td>
<td>W74G 494</td>
<td>W74G 465</td>
<td>W74G 343</td>
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<td>W58G 12420</td>
<td>W83G 16110</td>
<td>W74G 8240</td>
<td>W74G 8060</td>
<td>W74G 6280</td>
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<tr>
<td>W58G 1333</td>
<td>W83G 2270</td>
<td>W74G 567</td>
<td>W74G 762</td>
<td>W74G 571</td>
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<tr>
<td>W58G 62</td>
<td>W83G 210</td>
<td>W74G 194</td>
<td>W74G 204</td>
<td>W74G 188</td>
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<tr>
<td>W58G 0.153</td>
<td>W83G 0.217</td>
<td>W74G 80.75</td>
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<tr>
<td>W58G 12</td>
<td>W83G 6</td>
<td>W74G 5</td>
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<td>W74G 4</td>
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<table>
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<th>Precast Girder Projects</th>
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<td></td>
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<table>
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<tr>
<th>Strand Extension Alternative</th>
<th>3</th>
<th>1 or 2</th>
<th>1 or 2</th>
<th>1 or 2</th>
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6th International Bridge Conference
WSDOT Standard Prestressed Girders

80% of All New Bridges are Precast Girders

Span Capability (ft) 1995

<table>
<thead>
<tr>
<th></th>
<th>NSC</th>
<th>HSC</th>
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<tr>
<td>W42G</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>W50G</td>
<td>90</td>
<td>100</td>
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<td>W58G</td>
<td>110</td>
<td>125</td>
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<td>W74G</td>
<td>130</td>
<td>145</td>
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</table>
STANDARD WIDE FLANGE GIRDERS

<table>
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<tr>
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<th>Span Capability, ft</th>
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<tr>
<td>WF42G</td>
<td>110</td>
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<tr>
<td>WF50G</td>
<td>125</td>
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<tr>
<td>WF58G</td>
<td>140</td>
</tr>
<tr>
<td>WF74G</td>
<td>165</td>
</tr>
<tr>
<td>W83G</td>
<td>180</td>
</tr>
<tr>
<td>W95G</td>
<td>190</td>
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</tbody>
</table>
Span Capability Comparison

WF42G vs. W42G

WF58G vs. W58G

WF74G vs. W74G
Bridge Superstructure Replacement
Girder Efficiency

Existing Bridge (1992 Design)
15 – W74G Girders
• $f_c = 6.0 \text{ ksi}$
• $f_{ci} = 5.0 \text{ ksi}$
• 0.5” φ Strands

New Bridge (2003 Design)
8 – WF74G Girders
• $f_c = 10.0 \text{ ksi}$
• $f_{ci} = 7.5 \text{ ksi}$
• 0.6” φ Strands
WSDOT TRAPEZOIDAL TUB GIRDERS

Span Capability, ft

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>U54G4</td>
<td>130</td>
</tr>
<tr>
<td>U66G4</td>
<td>155</td>
</tr>
<tr>
<td>U78G4</td>
<td>170</td>
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<tr>
<td>UF60G4</td>
<td>150</td>
</tr>
<tr>
<td>UF72G4</td>
<td>165</td>
</tr>
<tr>
<td>UF84G4</td>
<td>185</td>
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</table>
### STANDARD SPLICED I-GIRDERS

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>PT Before</th>
<th>PT After</th>
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<tbody>
<tr>
<td>WF74PTG</td>
<td>165</td>
<td>180</td>
</tr>
<tr>
<td>W83PTG</td>
<td>185</td>
<td>205</td>
</tr>
<tr>
<td>W95PTG</td>
<td>200</td>
<td>235</td>
</tr>
</tbody>
</table>

*Span Capability, ft*

- WF74PTG: 185 ft
- W83PTG: 200 ft
- W95PTG: 235 ft

**PCI Award**

6th International Bridge Conference 20
Precast HSC Spliced I-Girders

(Riverside Bridge)

- Precast Superstructure
- Hinge Connections at Piers

PCI Award
STANDARD HSC SPLICED U-GIRDERS

TRAPEZOIDAL TUB SECTION

<table>
<thead>
<tr>
<th>Span Capability, ft</th>
<th>U54PTG6</th>
<th>U66PTG6</th>
<th>U78PTG6</th>
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<tbody>
<tr>
<td></td>
<td>145</td>
<td>165</td>
<td>190</td>
</tr>
</tbody>
</table>

PCI Award

6th International Bridge Conference
Precast Spliced Girder- Fixed Diaphragm

S. 38th Street Bridge
Precast Stay-in-Place Deck Panel

S. 38th Street Bridge
Precast Spliced Girder- Fixed Diaphragm

(Green River Bridge)

- Precast Superstructure
- Hinge Connections at Piers
SURVEY: Use of Precast Members in Bridge Construction

Superstructure: PCI Seismic Design Survey

Domestic

- Number of States:
  - YES: 22 (82%)
  - NO: 5 (18%)

Foreign

- Number of Countries:
  - YES: 6 (100%)
  - NO: 0 (0%)
**SURVEY:** Use of Precast Members in Bridge Construction

*Substructure:*

**Domestic**

- YES: 6 (24%)
- NO: 19 (76%)

**Foreign**

- YES: 4 (67%)
- NO: 2 (33%)

*PCI Seismic Design Survey*
PCI Seismic Design Subcommittee Survey

Difficulties in using Precast Bridges

- Lack of Design and Detailing Guidelines
- Availability of Construction equipments
- Lack of construction specifications
- Long-term performance & maintenance concerns
- Connection Details Meeting Seismic Requirements
- Cost competitive with C-I-P
- Cost of Fabrication and Shipping
- Site and Soil Condition for Crane Load, etc
- Need for Small Demonstration Projects
Precast Substructures
PCI Seismic Design Subcommittee

State of the Practice Repost outlines

1. Introduction
2. Seismic Criteria
3. Seismic Analysis
4. Structural System Considerations
5. Connection Details
6. Current Practice
7. Good detailing practices
8. Design Examples
9. Applicable Current Research
Precast Column on Shaft

- Precast Girders
- Column reinforcement
- Precast Column
- Precast Column Erection Support
- Confinement Zones
- Construction Joint
- Cast-In-Place Bent Cap
- PreCast Column
- Cast-In-Place Shaft
- PreCast Column Erection Support

6th International Bridge Conference
Precast Column on Spread Footing
Precast Slanted Column on Spread Footing

- CIP superstructure
- Precast Column
- Column reinforcement
- Precast Column Erection Support
- CIP Footing
- Support Pad
Precast Slanted Column on Spread Footing
Column Test for Seismic (UNR)

Reduced Scale Test Specimen
Precast System (monolithic connections)

Plan (Precast Bent Cap)

Section A

Completed Precast System with monolithic connections

Precast Column

Joint reinforcement

Column reinforcement

Seat for Precast Bent Cap (12” Min)

Precast Column Erection Support
Precast System (monolithic connections)

- Cast-in-place Diaphragm
- Precast Bent Cap
- Confinement Zones
- Precast Column
- Support Pad
- Cast-in-place Slab
- 3” thick Rubber Pad
- Precast Column
- Cast-In-Place Shaft
Precast System — Precast Deck (monolithic connections)

- Precast Column
- Cast-in-place Slab
- 3” thick Rubber Pad
- Cast-In-Place Shaft
- Precast Column
- Precast Bent Cap
- Precast Column
- Cast-in-place Diaphragm
- Confinement Zones
- Support Pad
- 3” thick Precast System – Precast Deck (monolithic connections)
## Numerical Application

(Precast column to Precast Bent cap)

<table>
<thead>
<tr>
<th></th>
<th>Bottom of Column</th>
<th>Top of Column</th>
<th>Top of Column</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Column Diameter, ft</strong></td>
<td>6</td>
<td>4</td>
<td>6 (4 at Recess)</td>
</tr>
<tr>
<td><strong>Axial Load, kips</strong></td>
<td>1945</td>
<td>1869</td>
<td>1869</td>
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<tr>
<td><strong>Seismic Elastic Moment, ft-kips</strong></td>
<td>22530</td>
<td>21360</td>
<td>18360</td>
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<tr>
<td><strong>Reduced Moment, ft-kips</strong></td>
<td>4506</td>
<td>4272</td>
<td>3672</td>
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<tr>
<td><strong>Reinforcement Ratio</strong></td>
<td>1%</td>
<td>3.75%</td>
<td>3.25%</td>
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<tr>
<td><strong>Resistance Factor</strong></td>
<td>0.75</td>
<td>0.68</td>
<td>0.68</td>
</tr>
<tr>
<td><strong>Plastic Hinging Moment, ft-kips</strong></td>
<td>8406</td>
<td>8390</td>
<td>7212</td>
</tr>
</tbody>
</table>
Ongoing Research With University of WA

6" φ Hole in Crossbeam for 1-3/8" φ –150 ksi Bar Tendons

ELEVATION

PLAN
Ongoing Research With University of WA

Inverted Precast T-Beam

Hole for Extended strands and #7 bars
Precast Pedestrian/Bike Bridge

- Precast Superstructure
- Precast Column
- Fixed Connections at Piers

80’-0”  80’-0”

Precast Variable Depth Tub

Cast-in-place Ductile joints

Precast Column
Conclusions - 1

- Precast bridges are effective system for Accelerated bridge construction.
- Monolithic connections meeting seismic Design and Detailing requirements shall be considered.
- Extended strands in bottom flange provide positive flexural capacity to resist EQ Forces.
- Construction Tolerances shall be Considered.
- Long-term performance & maintenance concerns.
Conclusions – 2

- Lack of Design and Detailing Guidelines
- Lack of construction specifications
- Availability of Construction equipments
- Cost competitiveness with C-I-P Alternative
- Fabrication and Shipping Cost
- Site and Soil Condition for Crane Load and Placement
- Need for Demonstration Projects