ABC ACCELERATED BRIDGE CONSTRUCTION UNIVERSITY TRANSPORTATION CENTER

FIU FLORIDA INTERNATIONAL UNIVERSITY

Home Research Education Webinars Resources Conference Events News

ABC-UTC 2023 In-Depth Web Training
Module 2 – 9/12/23
Washington State's I-5 / US 12 Bridge at Grand Mound Precast Substructure

Owner's Perspective: Amy Leland, PE, SE
State Bridge Design Engineer, WSDOT

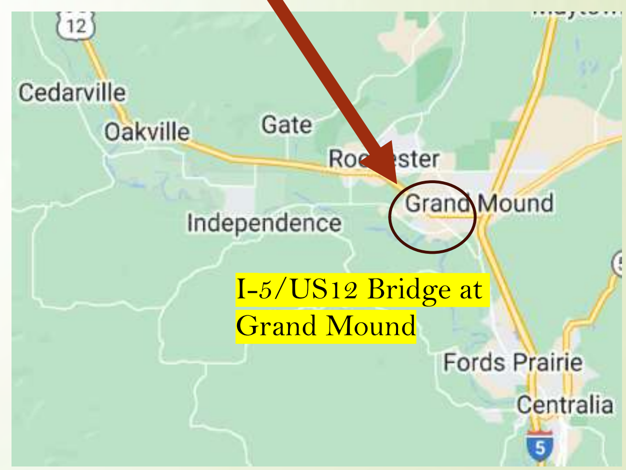
Khashayar Nikzad, PhD, PE
Principal Engineer, TranTech Engineering

Bijan Khaleghi, PhD, PE, SE
Principal Structural Engineer, TranTech Engineering,
Research Associate Professor, Director of Implementation
Florida International University - ABC-UTC

Washington State Department of Transportation

TRANTECH Engineering LLC DBE Certified Bellevue Bellingham Pasco Olympia

Bridge Location Map: Washington State's I-5 / US 12 Bridge at Grand Mound



Washington State Department of Transportation

TRANTECH Engineering LLC
DBE Certified
Bellevue
Bellingham
Pasco
Olympia

Module 2 Description

The 2023 in-depth web training features the Accelerated Bridge Construction (ABC) in moderate-to-high seismic regions, with a particular emphasis on seismic connections used for Washington State's I-5 / US 12 Bridge at Grand Mound Precast Substructure ABC project

Outline:

- Introduction and WSDOT Remarks
- Bridge Seismic Design Consideration in Washington State
- ABC Bridge Design Specifications and BDM Requirements
- Design and Detailing Requirements for Seismic Connections
- Fabrication and Construction Challenges
- Lesson Learned and Concluding Remarks

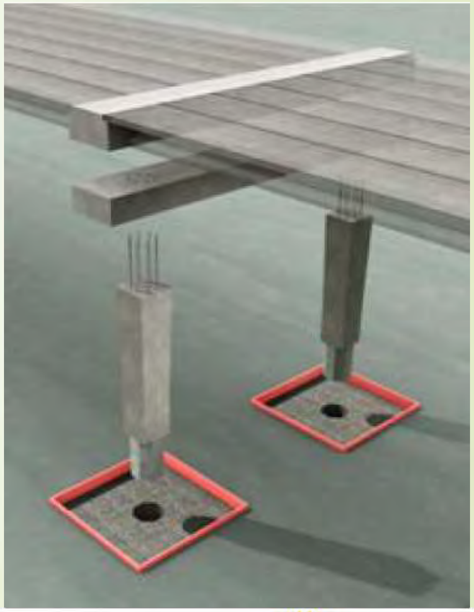
Module 2: Washington State's I-5 / US 12 Bridge at Grand Mound Precast Substructure

1. **Introduction and WSDOT Remarks**
2. Design and Detailing Requirements
3. Fabrication and Construction Challenges
4. Lesson Learned and Concluding Remarks

Highways for LIFE – Demonstration Project

The purpose of Highways for LIFE (HfL) was to advance longer-lasting highway infrastructure using innovations to accomplish the Fast construction of Efficient and safe highways and bridges. The three goals of HfL were to:

- 1-improve safety during and after construction,
- 2-reduce congestion caused by construction, and
- 3-improve the quality of the highway infrastructure.



Precast Bent System for High Seismic Regions

- Socket connection at the column-to-foundation connection and grouted-ducts at columns, and column-to-cap beam connection.
- Connections designed to be capacity protected
- The lower column socket connection has also been configured to be used with spread footings and Shafts.

Examples of WA Accelerated and Innovative Bridge Construction

Lateral Sliding

- I-5, Skagit River Bridge – Bridge Replacement Mount Vernon, Washington
- SR 104, Hood Canal Bridge–West Approaches–Port Gamble, Washington

Precast Crossbeam

- SR 16, Eastbound Nalley Valley Tacoma, Washington
- I-5, Highways for Life Demonstration Project–Grand Mound, Washington
- SR 520, Floating Bridge Seattle, Washington

Precast Column

- SR 520, 36th Street Bridge–Redmond, Washington
- I-405, NE 8th Street Ramp–Bellevue, Washington
- SR 16, Cedar Street and Union Avenue Bridges Tacoma, Washington

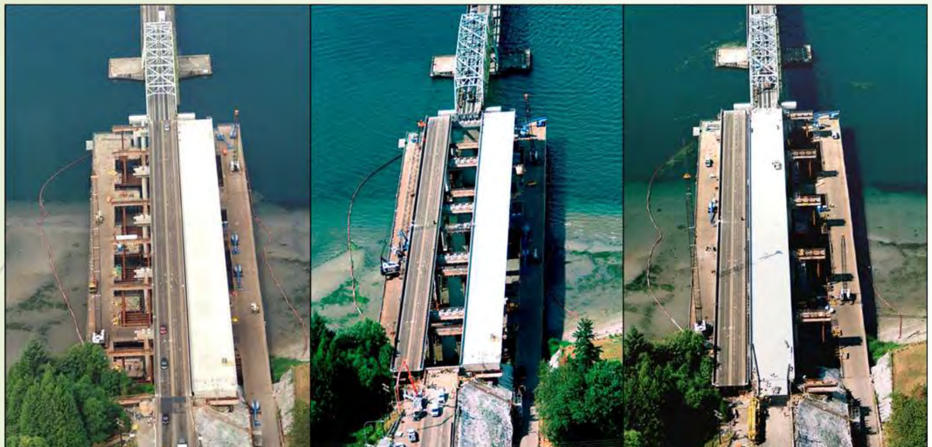
Self-Propelled Modular Transporter

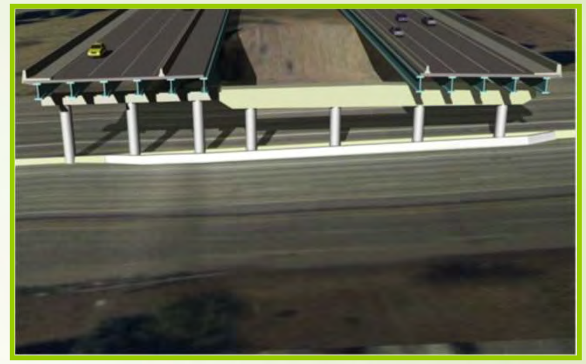
- SR 104, Hood Canal Bridge– East and West Approaches–Port Gamble, Washington
- SR 433, Lewis & Clark Bridge –Longview, Washington–Rainier, Oregon

Other Precast Elements

- SR 303, Manette Spliced Girder Bridge–Bremerton, Washington

Examples of WA Accelerated and Innovative Bridge Construction





Washington State Department of Transportation

TRANTECH Engineering LLC

DBE CERTIFIED

BELLEVUE
BELLINGHAM
PASCO
OLYMPIA

Examples of WA Accelerated and Innovative Bridge Construction

Module 2: ABC Substructure Grouted Ducts/Socket Connections in Washington State Bridge

1. Introduction and WSDOT Remarks
2. **Design and Detailing Requirements**
3. Fabrication and Construction Challenges
4. Lesson Learned and Concluding Remarks

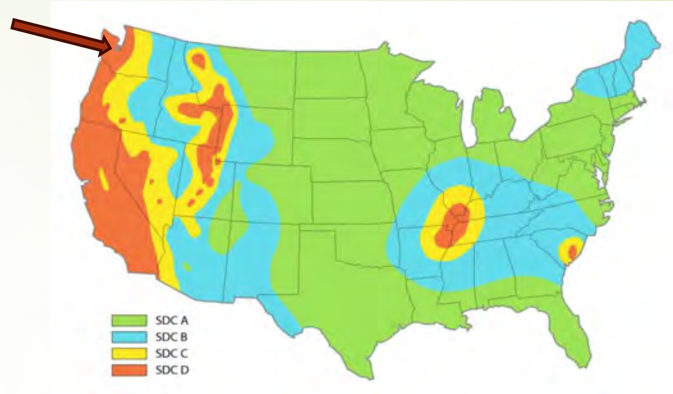
Washington State Department of Transportation

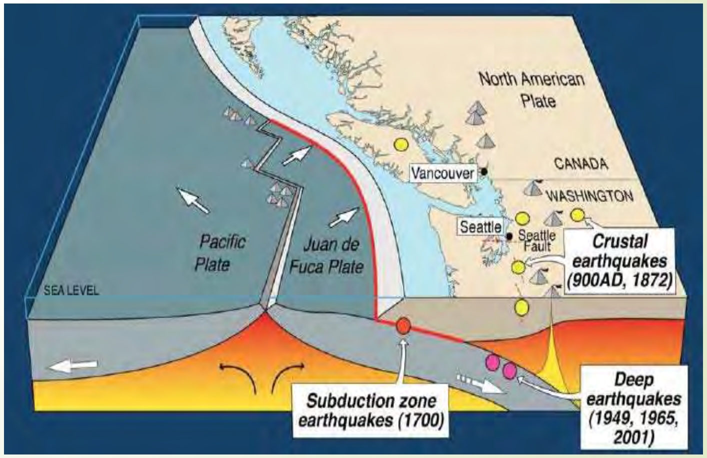
TRANTECH Engineering LLC
DBE Certified
Bellevue Bellingham Pasco Olympia

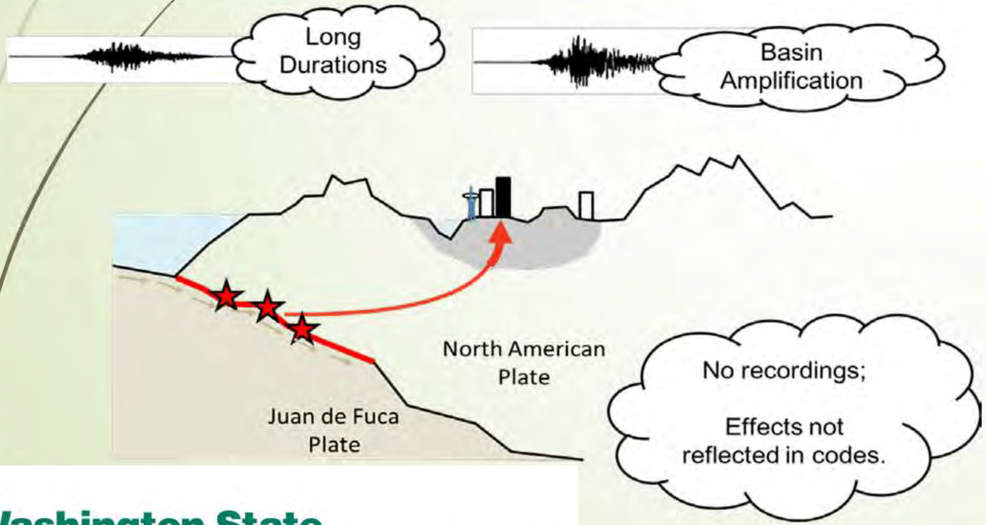
Seismicity of Washington State

Challenges with Seismic Design

- Cascadia Subduction Zone
- M9 Long Duration Mega EQ
- Basin Effect and Liquefaction
- Lifeline Considerations







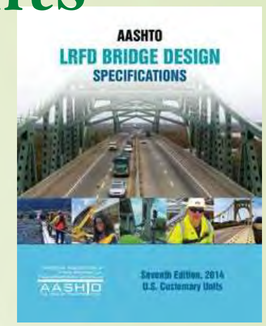
Washington State Department of Transportation

TRANTECH Engineering LLC
DBE Certified
Bellevue
Bellingham
Pasco
Olympia

11

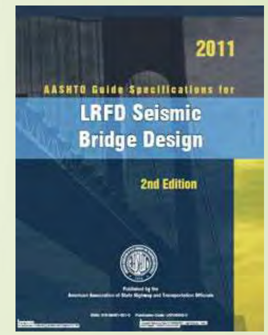
Need for Seismic Design: Examples of Bridge Earthquake Damages

LRFD Seismic Design and ABC Requirements



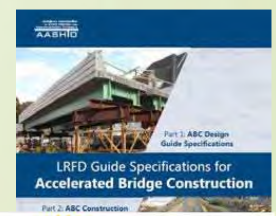
- **LRFD Bridge Design Specifications**

  Bridges shall be designed for specified limit states to achieve the objectives of constructability, safety, and serviceability, inspectability, economy, and aesthetics.



- **Guide Specifications for LRFD Seismic Bridge Design**

  Design and construction of conventional bridges to resist the effects of earthquake motions.



- **LRFD Guide Specifications for ABC**

  The provisions are for common prefabricated elements and systems for Accelerated Bridge Construction (ABC) projects.

Washington State Department of Transportation

TRANTECH Engineering LLC — DBE Certified — Bellevue, Bellingham, Pasco, Olympia

AASHTO LRFD Guide Specifications for ABC:

The ABC Guide Specs (NCHRP 12-102) is written as Supplement to:

- AASHTO LRFD Bridge Design Specifications and
- AASHTO Bridge Construction Specifications

The ABC Guide Specs includes Separate Design and Construction Parts:

Part 1: ABC Design Specifications

- Introduction
- General Design Provisions
- Design of Prefabricated Elements
- Detailing Requirements
- Durability of ABC Technologies

Part 2: ABC Construction Specifications

- Introduction
- Fabrication and Assembly Planning
- Layout and Tolerances
- Concrete Structures
- Steel Structures

Considerations for Balanced Stiffness - ABC

Balanced Stiffness Concept for Frames, Bents and Columns

- Between any two bents within a frame or between any two columns within a bent

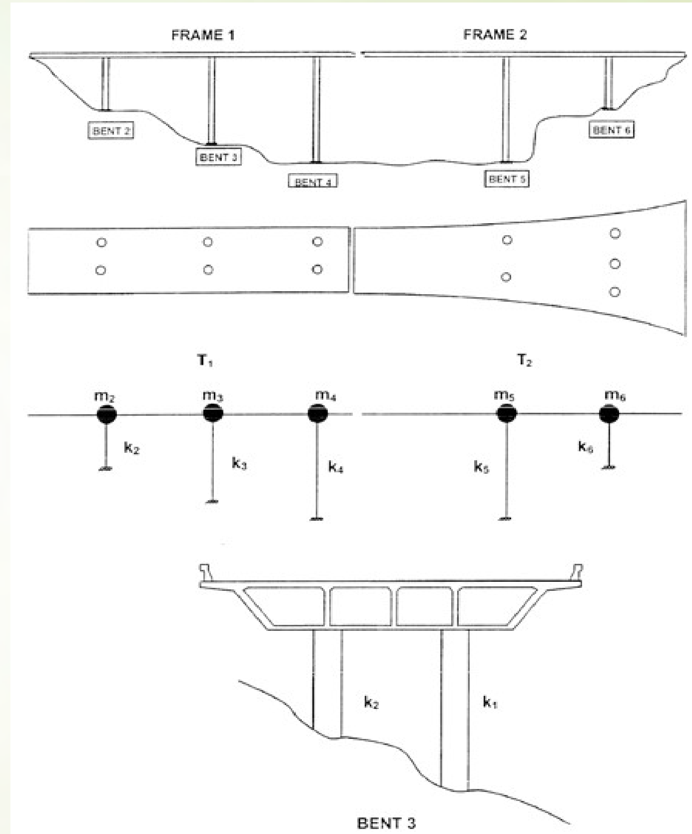
$$\frac{k_i^e}{k_j^e} \geq 0.5 \qquad \frac{K_i^e \times m_j}{K_j^e \times m_i} \geq 0.50$$

- Between adjacent bents within a frame or between adjacent columns within a bent

$$\frac{k_i^e}{k_j^e} \geq 0.75 \qquad \frac{K_i^e \times m_j}{K_j^e \times m_i} \geq 0.75$$

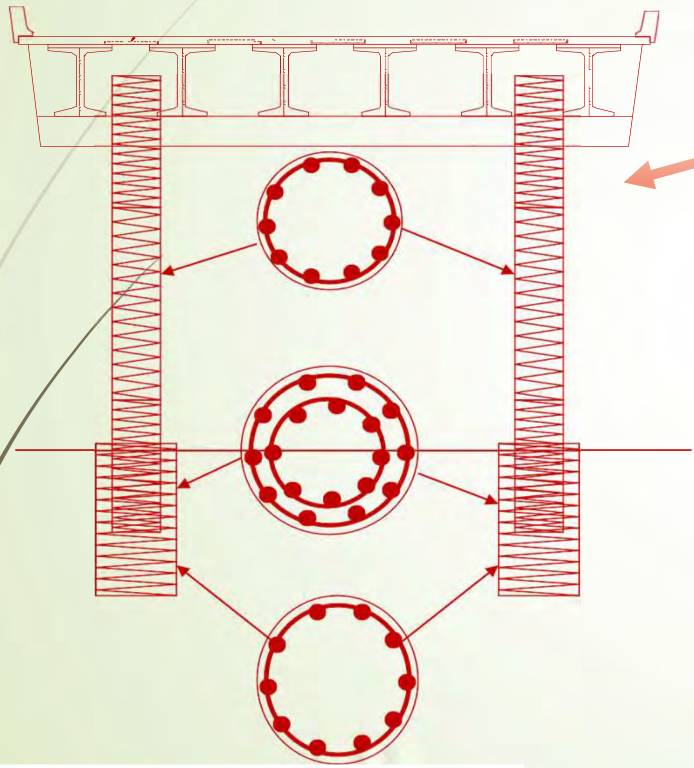
- Balanced Frame Geometry - (ratio of fundamental periods of vibration)

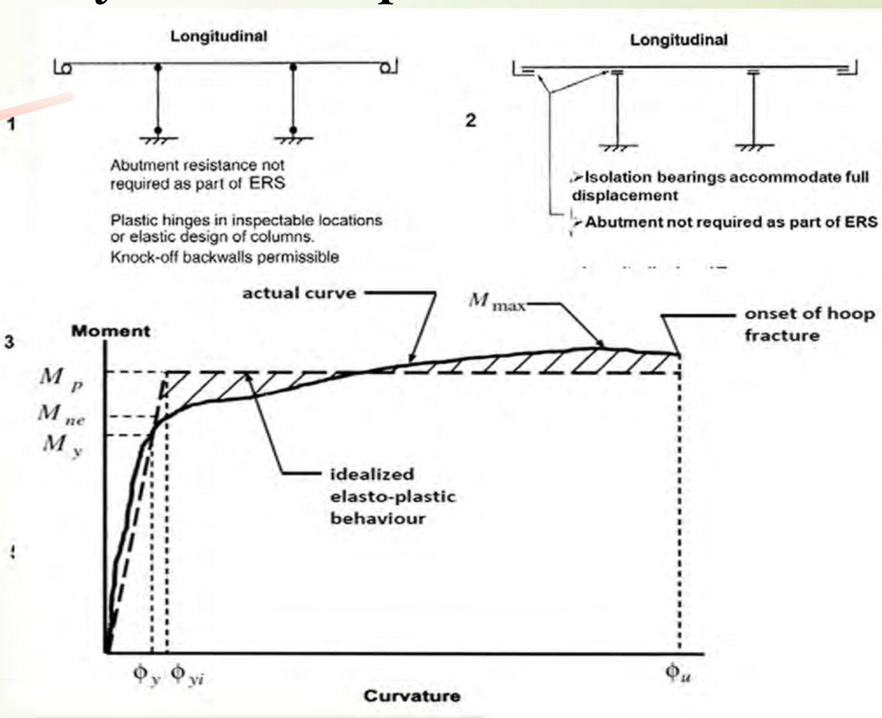
$$\frac{T_i}{T_j} \geq 0.7$$



Bridge Seismic Design Requirements

ERS and ERE to ensure required seismic performance for **Type 1:Ductile Substructure with Essentially Elastic Superstructure.**

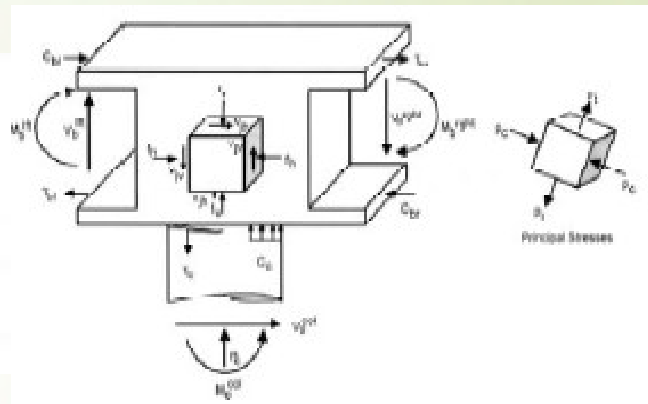




Other Bridge Seismic Design Requirements

Capacity Design Requirement for SDCs B, C and D

- M_{po} = 1.25 times the moment demand



- For principal compression, p_c:

$p_c \leq 0.25 f'_c$

$$p_t = \left| \left(\frac{f_h + f_v}{2} \right) - \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2} \right|$$

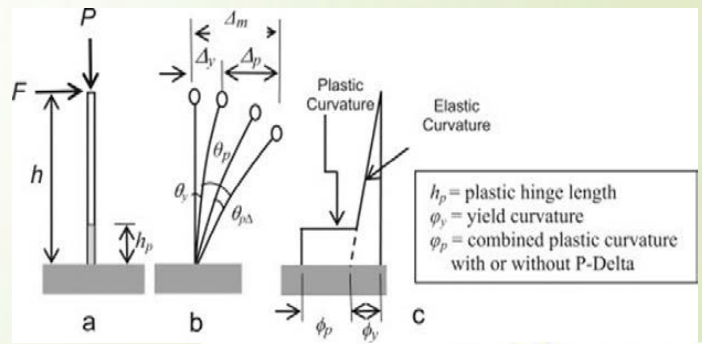
- For principal tension, p_t:

$p_t \leq 0.38 \sqrt{f'_c}$

$$p_c = \left(\frac{f_h + f_v}{2} \right) + \sqrt{\left(\frac{f_h - f_v}{2} \right)^2 + v_{jv}^2}$$

P-Δ effects Requirement: Ignore if:

- For reinforced concrete columns: $P_{dl}\Delta_r \leq 0.25 M_p$
- For steel columns: $P_{dl}\Delta_r \leq 0.25 M_n$



Maximum axial load acting on a column: $Pu < 0.2\ f'_c A_g$

Washington State Department of Transportation

TRANTECH Engineering LLC

DBE Certified

Bellevue
Bellingham
Pasco
Olympia

Design and Detailing: Joint Detailing Considerations

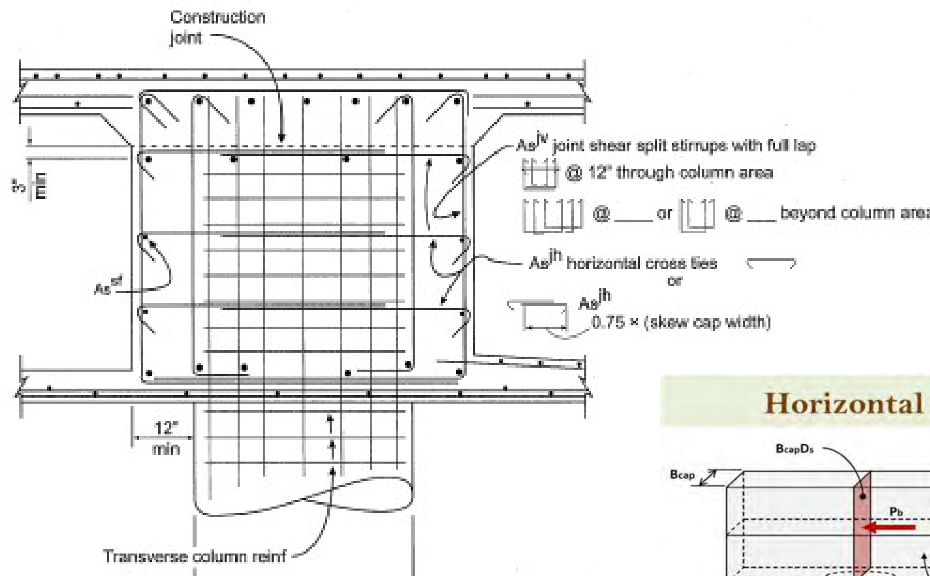
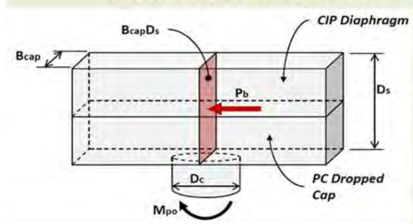


Figure 8.13.4.1.2a-2—Joint Shear Reinforcement Details

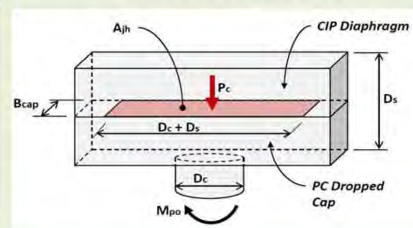
- Provide sufficient reinf. to resist seismic forces, and principal tension stresses for "integral joints"

Horizontal Stress



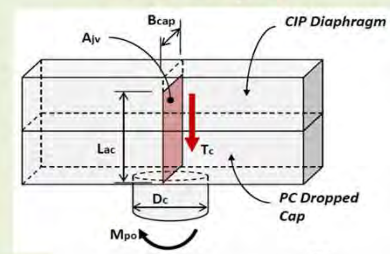
$$f_{h,PSC} = \frac{P_b}{B_{cap}D_{s1}}$$

Vertical Stress



$$f_{v,min} = \frac{P_{c,min}}{A_{jh}} = \frac{P_{c,min}}{B_{cap}(D_c + D_s)}$$

Joint Depth



$$v_{jv} = \frac{T_c}{A_{jv}} = \frac{T_c}{L_{ac}B_{cap}}$$

Post EQ Ductility Demand Limits

- Safety Evaluation Earthquake (SEE) spectrum based on a 7% probability of exceedance in 75 years.
- Functional Evaluation Earthquake (FEE) spectrum based on a 30% probability of exceedance in 75 years.

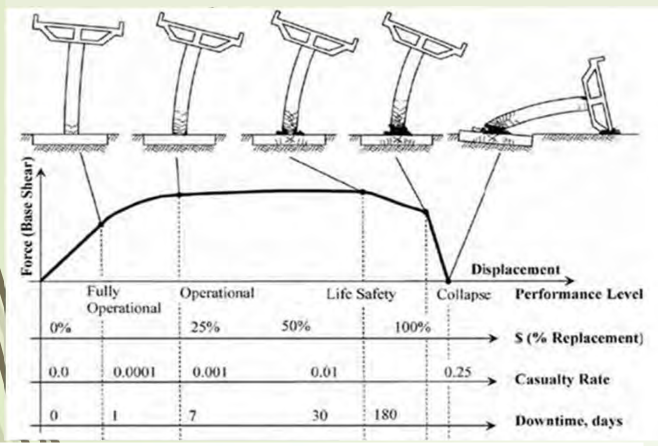


Table 4.1-1 Seismic Hazard Evaluation Levels and Expected Performance

Bridge Operational Importance Category	Seismic Hazard Evaluation Level	Expected Post Earthquake Damage State	Expected Post Earthquake Service Level
"Ordinary Bridges" – Eastern Washington	SEE	Significant	No Service
"Ordinary Bridges" – Western Washington (Not Lifeline)	SEE	Significant	No Service
	FEE	Minimal	Full Service
"Recovery Bridges" (Lifeline)	SEE	Moderate	Limited Service
	FEE	Minimal	Full Service
"Critical Bridges"	SEE	Minimal to Moderate	Limited Service
	FEE	None to Minimal	Full Service

Table 4.1-2 Displacement Ductility Demand Values, μ_D

Seismic Critical Member	Displacement Ductility Demand Limits						
	Ordinary Bridges • EW	Ordinary Bridges – WW (Not Lifeline)		Recovery Bridges (Lifeline)		Critical Bridges	
	• SEE	SEE	FEE	SEE	FEE	SEE	FEE
Wall Type Pier in Weak Direction	5.0	5.0	1.5	2.5	1.5	1.5	1.0
Wall Type Pier in Strong Direction	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Single Column Bent	5.0	5.0	1.5	2.5	1.5	1.5	1.0
Multiple Column Bent	6.0	6.0	2.0	3.5	2.0	1.5	1.0
Pile/Shaft-Column with Plastic Hinge at Top of Column	5.0	5.0	2.0	3.5	2.0	1.5	1.0
Pile/Shaft-Column with Plastic Hinge Below Ground	4.0	4.0	1.5	2.5	1.5	1.5	1.0
Superstructure	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Washington State's I-5 / US 12 Bridge at Grand Mound Precast Substructure

1) LOWER PIER CAP

2) GIRDERS ERECTED

3) UPPER-STAGE CAP CAST

Precast Bridge System with Two-stage Integral Pier Cap

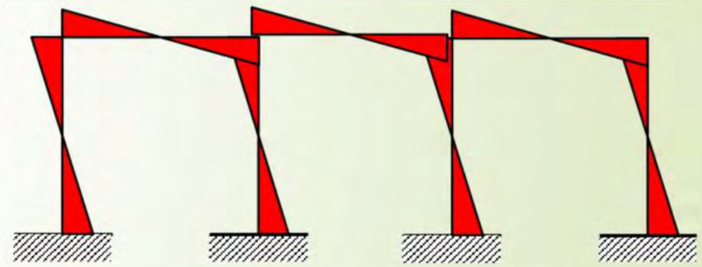
- **Owner:** Washington State DOT
- **Engineer:** Washington State DOT
- **Contractor:** Tri-State Construction
- **Precast Concrete:** Concrete Technology Corp.
- **Research:** University of Washington

Washington State Department of Transportation

TRANTECH Engineering LLC

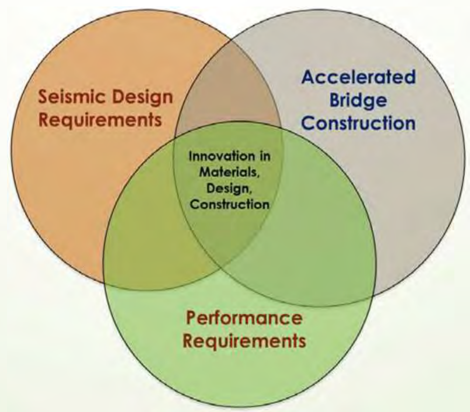
Bellevue Bellingham Pasco Olympia

Washington State's I-5 / US 12 Bridge at Grand Mound Precast Substructure



Features:

- Seismic Analysis & Design - Emulative
- Energy Dissipation and Capacity Protection
- Load path under load reversals
- Development of cyclic inelastic deformations
- Joint Proportioning for SDC C&D
- Long term Performance & Longevity
- Constructability

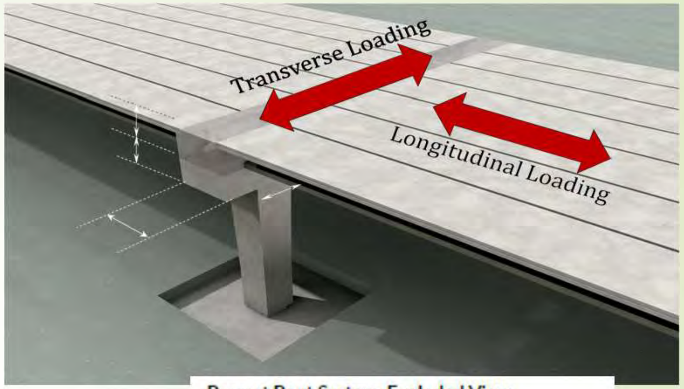


Design and Detailing - Seismic Design Approach

Step	Seismic Design using AASHTO SGS
1	Determine Seismic Input – Site Class C; SDC C
2	Establish Design Procedures
3	Identify the Earthquake Resisting System and Global Design Strategy – Type I Ductile Substructure, Owner's Approval Required for Precast Bent System (instead of conventional CIP bent system)
4	Perform Demand Analysis
5	Design and Check Earthquake Resisting Elements (Ductility Requirements) – Columns with Grouted Ducts and Socket Connections
6	Capacity Protect the Remaining Elements – Cap Beam, Spread Footing, Column Shear, Superstructure, etc

Design and Detailing: Type 1: Ductile Substructure with Essentially Elastic Superstructure

.



Precast Concrete Bent Cap

Stage 1 Bent Cap Design

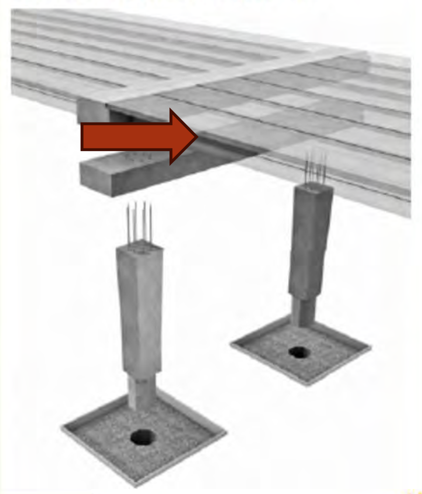
- Precast Pretensioned Beam
- Check Flexural, and Shear Capacity
- Check Flexural Capacity due to Weight of Wet Concrete and Girders

Stage 2 Bent Cap Design

- Superimposed Dead and Live Loads
- Seismic Displacement Demands & Capacity
- Check Flexural and Shear Capacity

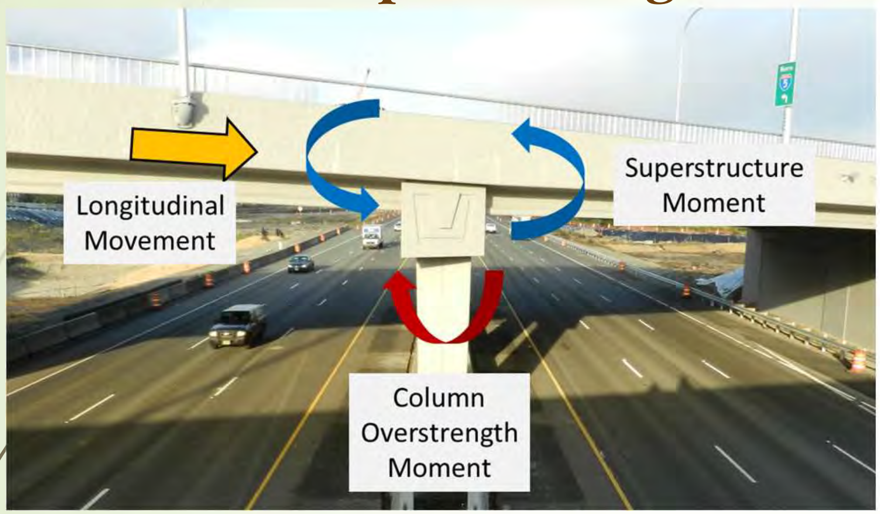
Additional Bent Cap Design Checks

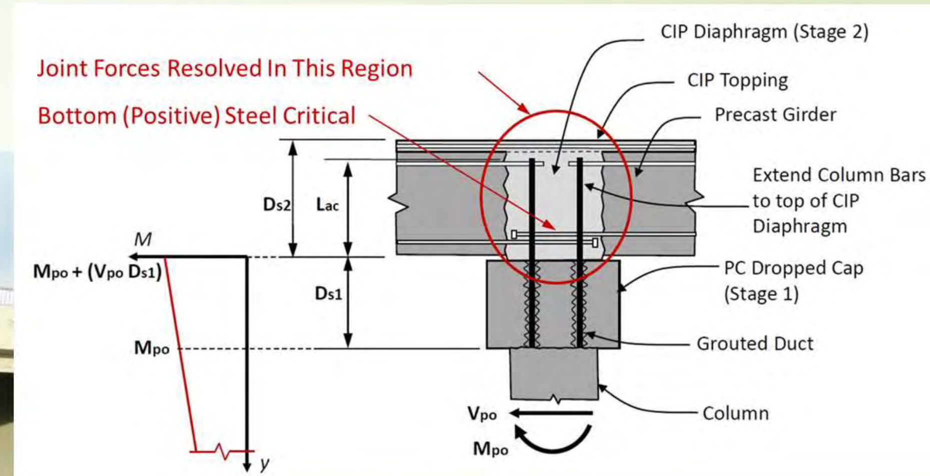
Precast Bent System, Exploded View

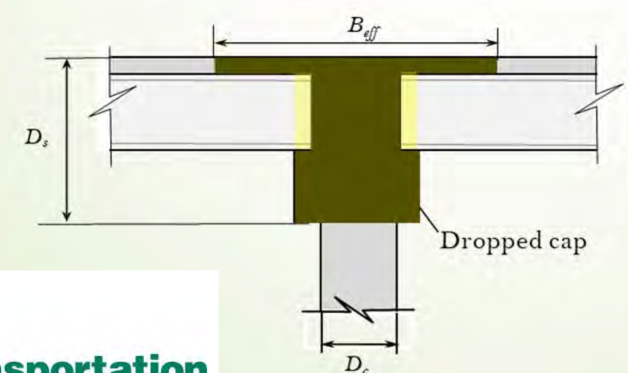


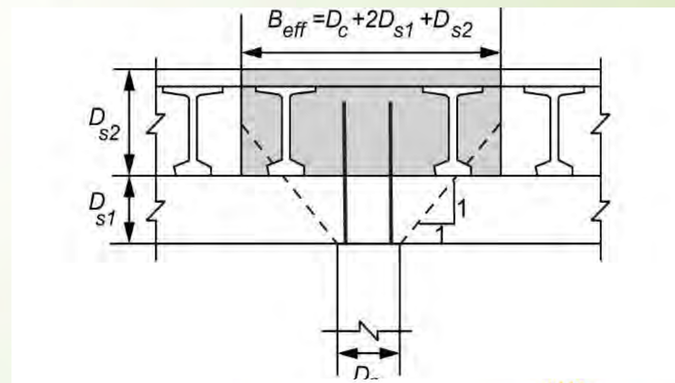
Design and Detailing: Longitudinal Joint Considerations

Integral Connections
Proportioning



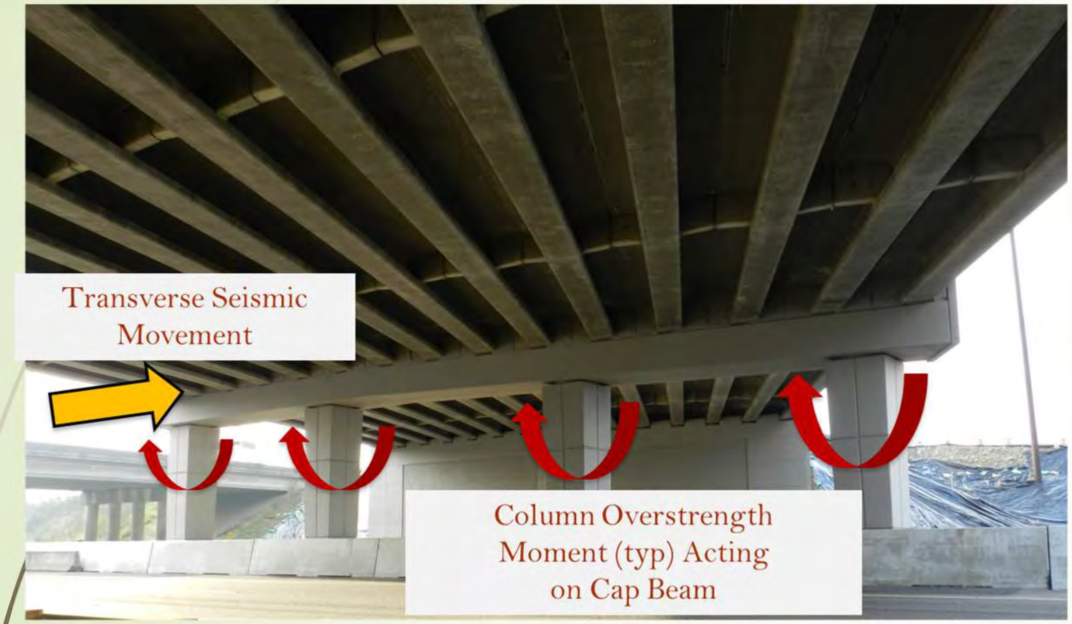


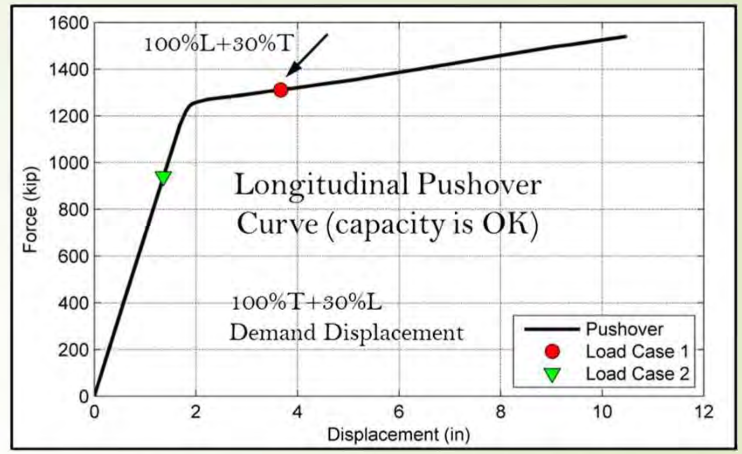


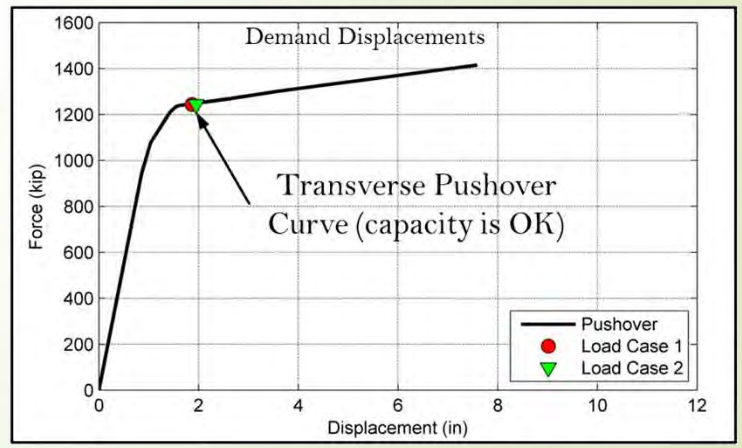


Effective Superstru
Longitudinal Dire

Integral Joint Design and Detailing Requirements







Displacement Capacity Checks: Transverse and Longitudinal Pushover

Washington State Department of Transportation

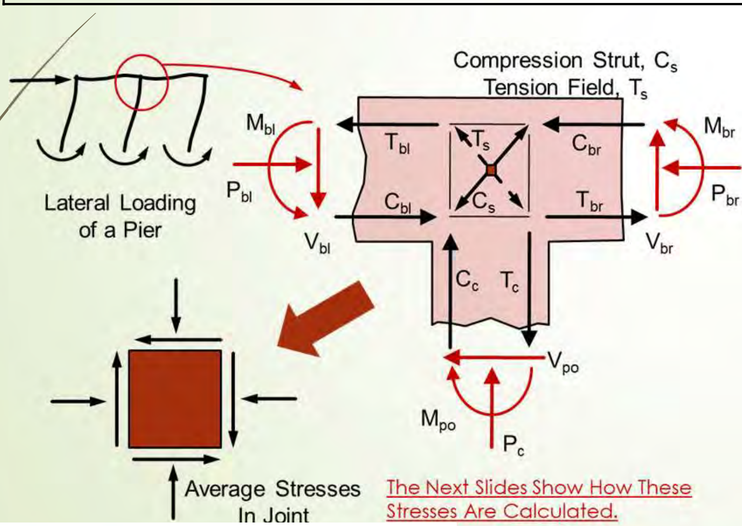
TRANTECH Engineering LLC

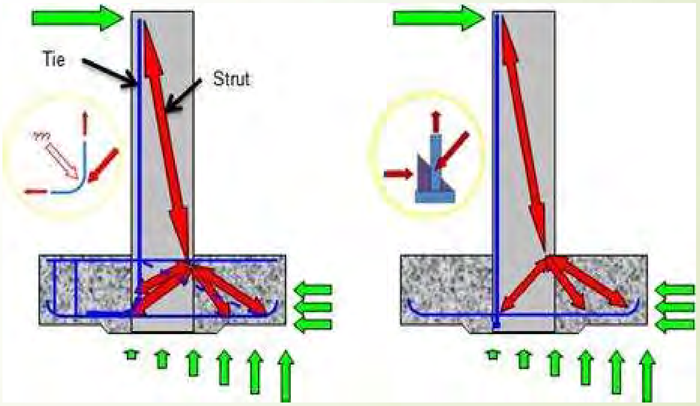
DBE Certified

Bellevue Bellingham Pasco Olympia

Bent Cap and Foundation Strut and Tie Models

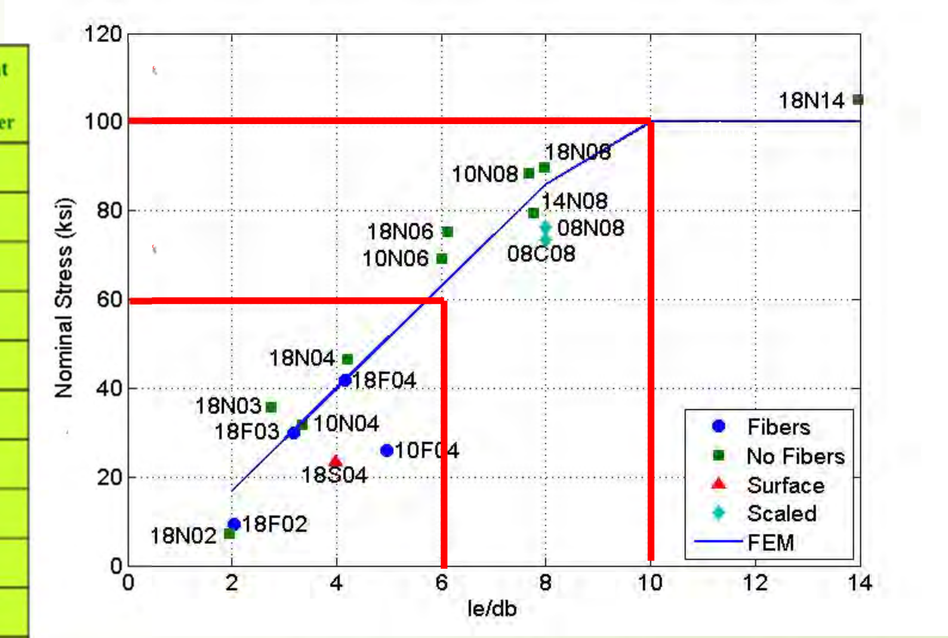
Strut and tie models for Column to Bent Cap Connection: for Two-Stage Integral Cap Beam	Strut and tie models for Column to Footing Socket Connection: (a) bent out bars and (b) headed bars.
• For <u>transverse loading</u> the full depth of cap beam is effective • For <u>longitudinal loading</u>, the upper portion of cap beam is effective	<u>Footing Socket Connection:</u> (a) Bent out bars and (b) Headed bars.





Grouted Bar-duct Pull-out Test Results

Bar Size	Nominal Duct Size, in.	Embedment Length, in.	Embedment / Bar Diameter
#3	2	12	29
#4	2.5	15	27
#5	3	15	21
#6	3	15	18
#7	3	20	21
#8	3.5	20	18
#9	3.5	20	16
#10	3.5	25	18
#11	4	25	16
#14	4	30	16
#18	4.5	40	16



Graph. Grouted bar-duct pull-out test results

Recommended Duct Size & Embedment Length – ABC

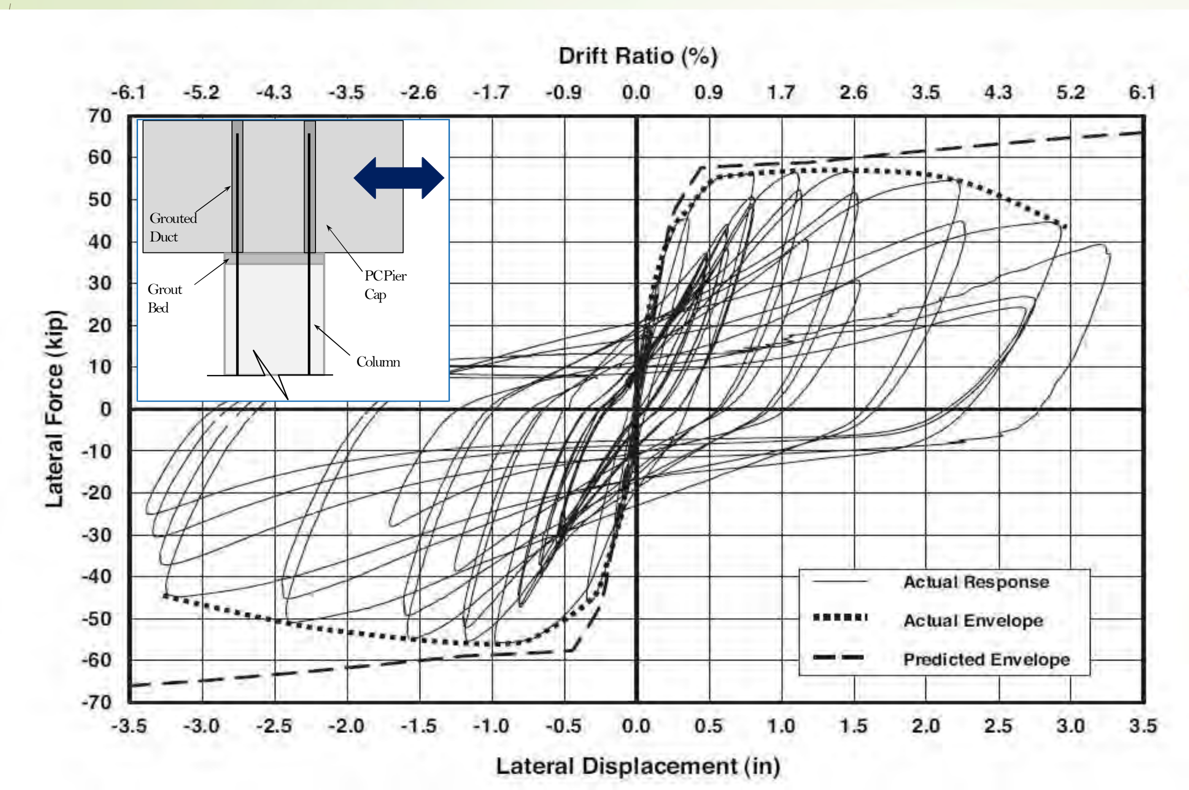
Washington State Department of Transportation

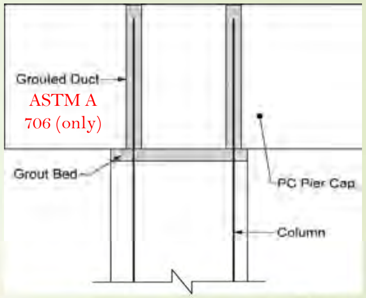
TRANTECH Engineering LLC

DBE Certified

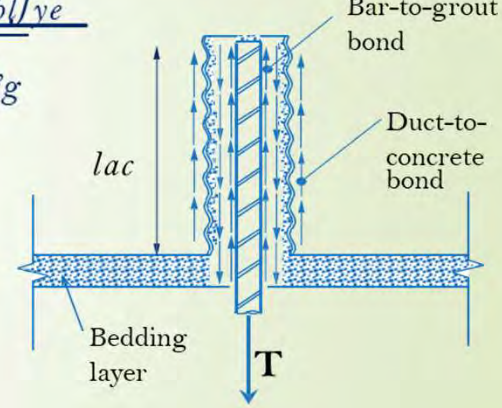
Bellevue Bellingham Pasco Olympia

Research Finding: Grouted Ducts Connection





$$l_{ac} = \frac{0.67 d_{bl} f_{ye}}{\sqrt{f'_{cg}}}$$



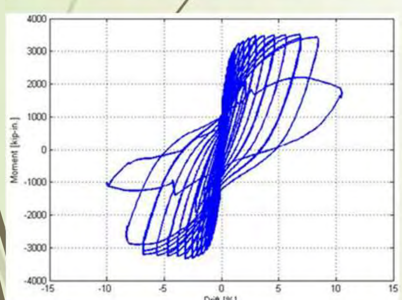
Connect reinforcing bars that projects from one element into a corrugated ducts embedded in receiving member

Equ
a ba

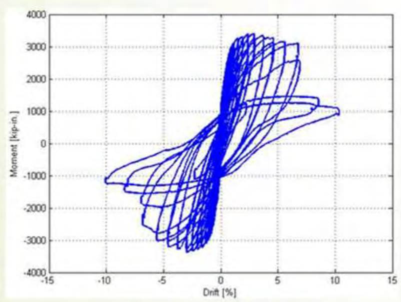
Column to Foundation Connections Construction and Test

Specimen DS-1 after testing.

Specimen DS-2 after testing.



Specimen DS-1 base moment-drift response.



Specimen DS-2 base moment-drift response.

Specimen construction (left) and specimen testing (right).

Washington State Department of Transportation

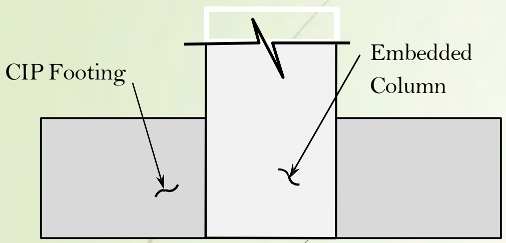
TRANTECH Engineering LLC

DBE Certified

Bellevue
Bellingham
Pasco
Olympia

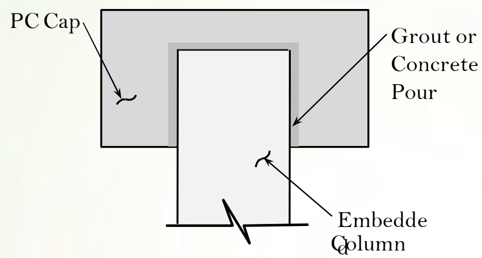
Research Finding: Socket Connection Details

- Embedment of precast column into receiving element
- Socket can be: **a) Wet (cast-in-place), b) Formed (precast)**



a) Wet (cast-in-place)

COLUMN IN CIP FOOTING



b) Formed (precast)

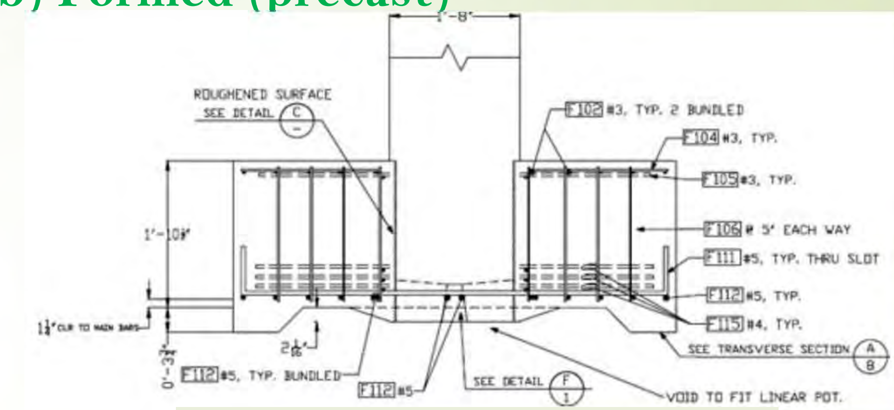
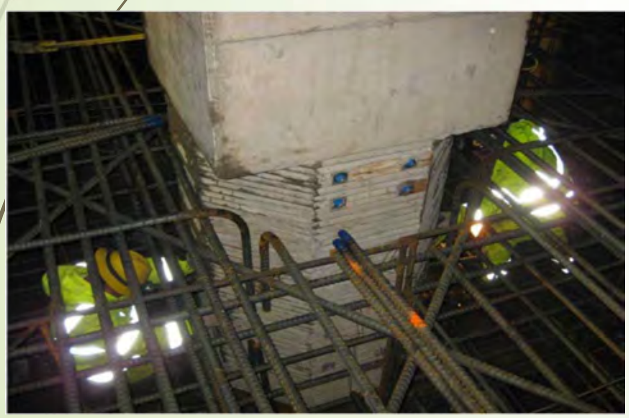


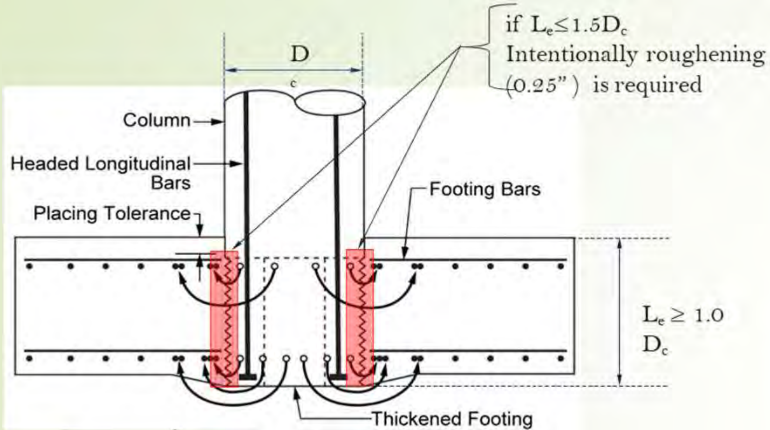
Diagram. Details of test specimen

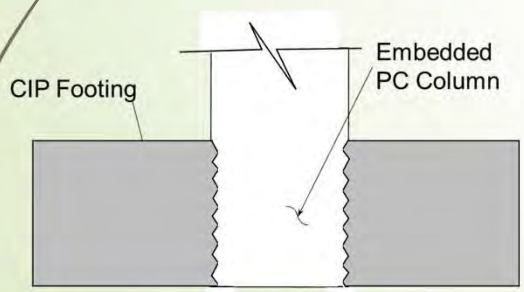


Source: Tran et al. (2013)

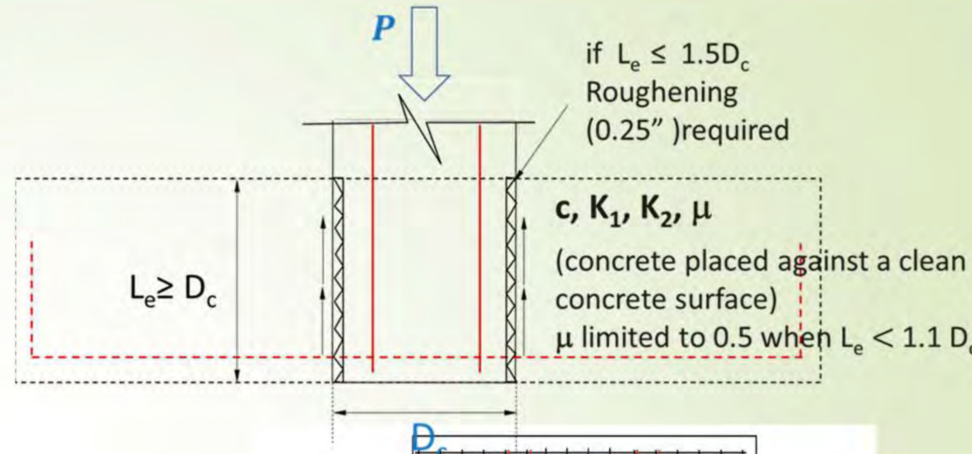
Design and Detailing

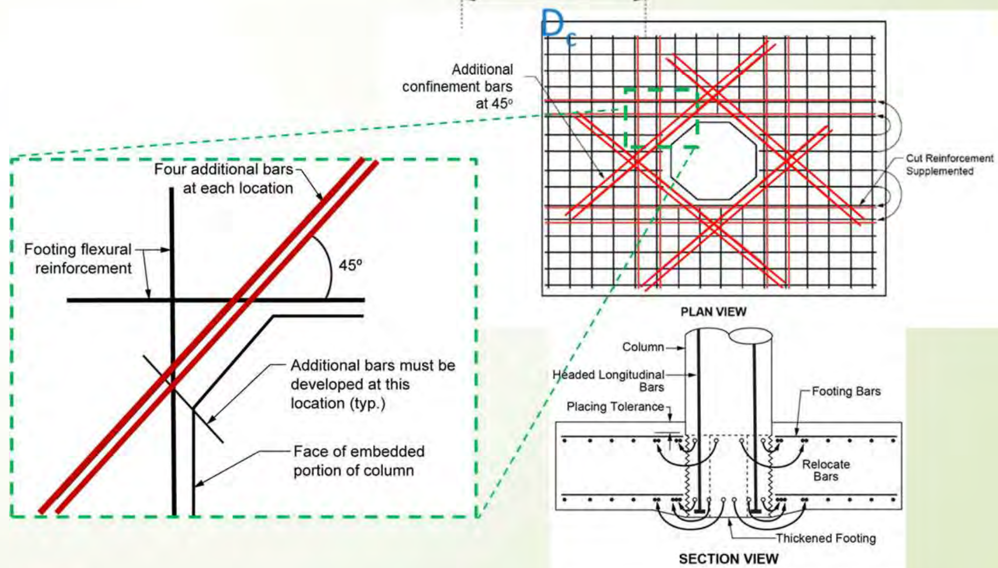
Socket Connections



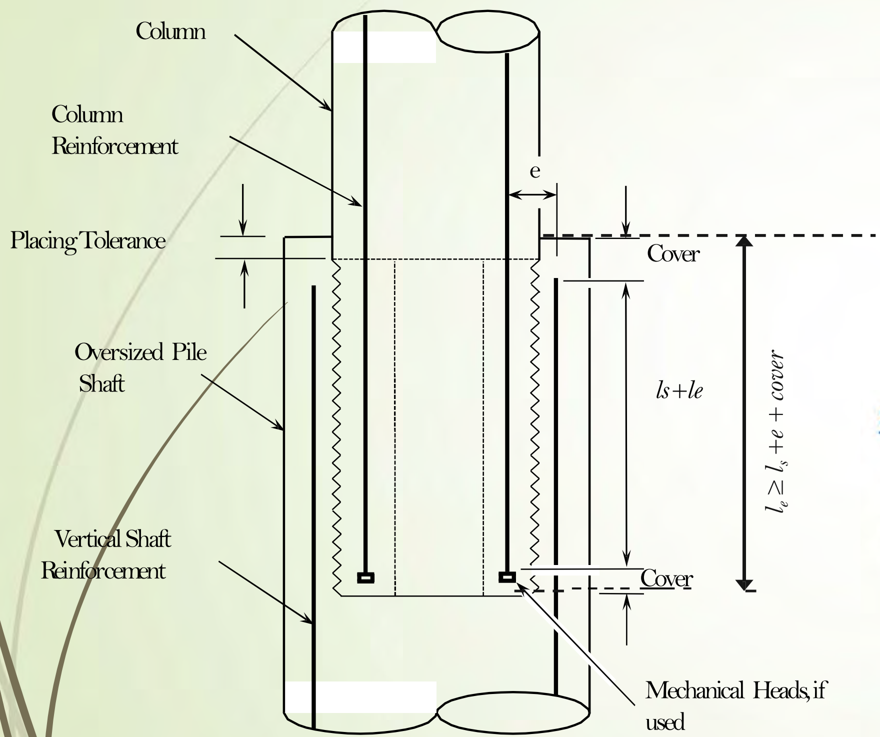


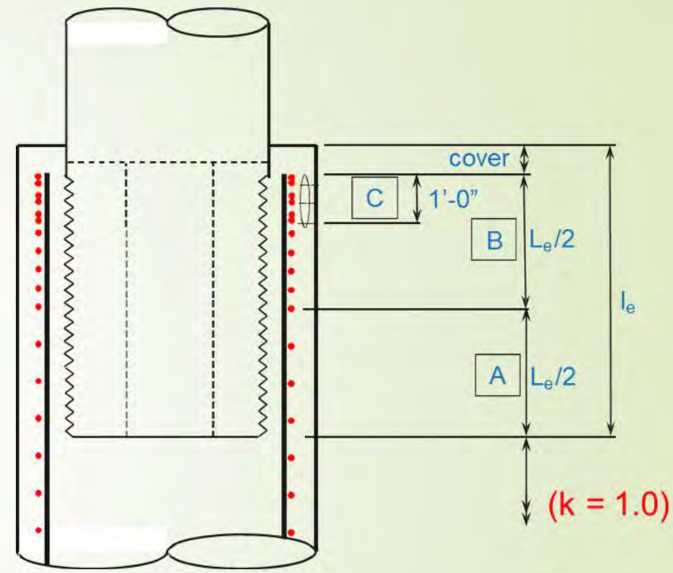
Wet (cast-in-place)





Design and Detailing: Socket Connection in Shaft





Spiral/Hoops Requirement

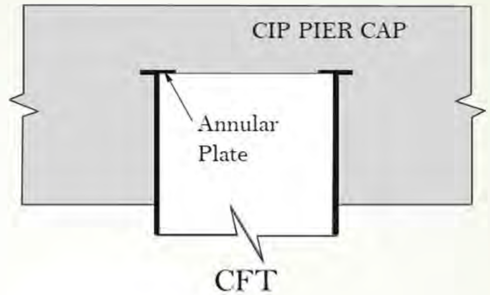
$$\frac{A_{sh}}{s_{max}} \geq \frac{k f_{ul} A_l}{2\pi f_{ytr} l_s}$$

Location

- A (k = 0.5)
- B (k = 1.0)
- C (k = 2.0)

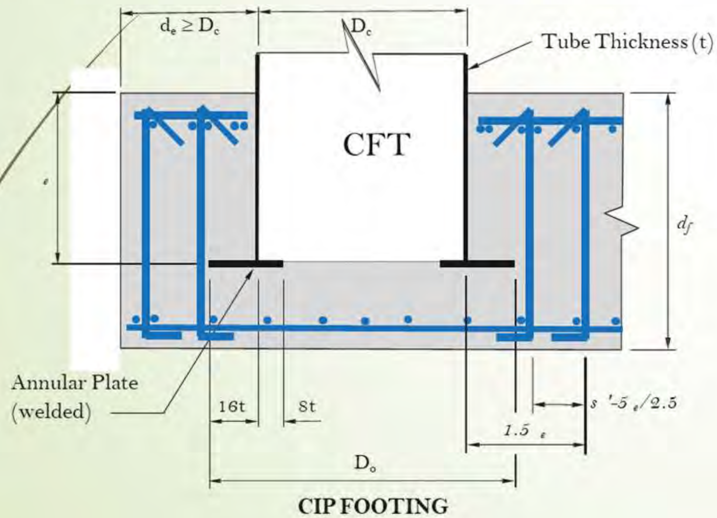
Socket Connections CFST in Socket (Emulative)

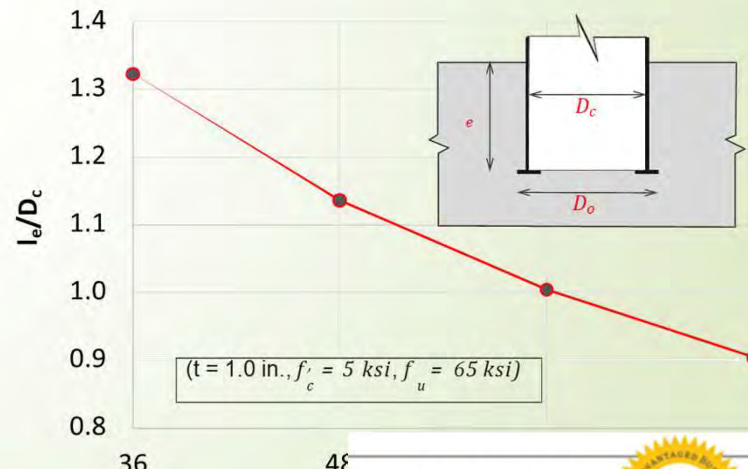
Eastbound Nalley Valley (WA)



$$l_e = \sqrt{\frac{D_o^2}{4} + \frac{1.2\, D_c\, t\, F_u}{0.19\sqrt{f'_{cf}}}} - \frac{D_o}{2}$$

$$D_f = \sqrt{\frac{D_c^2}{4} + \frac{(C_c + C_s)}{0.12\sqrt{f'_{cf}}}} - \frac{D_c}{2}$$





Module 2: ABC Substructure Grouted Ducts/Socket Connections in Washington State Bridge

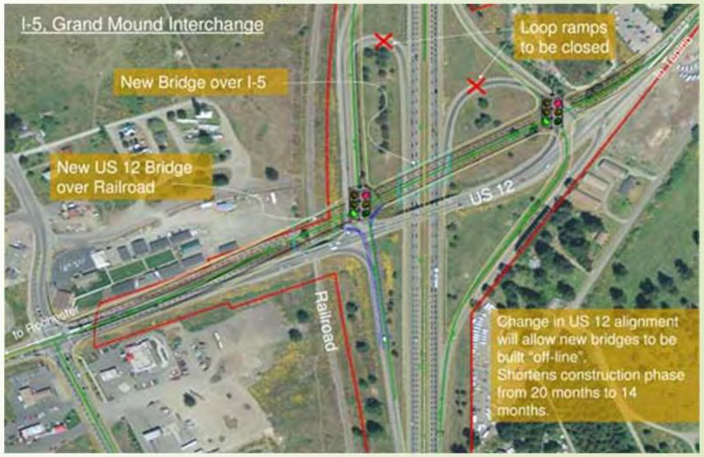
1. Introduction
2. Design and Detailing
3. **Fabrication and Construction**
4. Lesson Learned and Conclusions

WA I-5/US 12 Bridge Replacement Features

Fabrication and Construction

Substructure Construction:

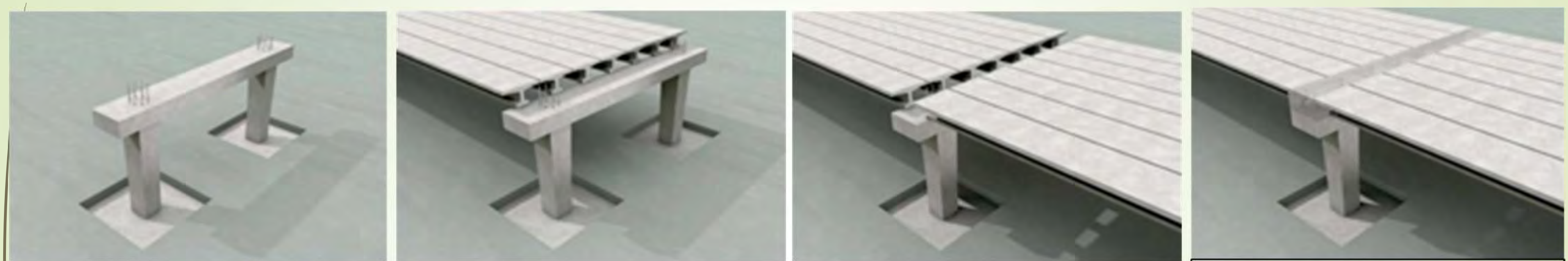
- Precast columns in segments
- Column to Cap Grouted Duct Connection
- Column Segment grouted Ducts Connection
- Precast Column to footing Socket connection
- Precast Pretensioned crossbeam segments



Footing Construction:

- Excavate for footing, Place leveling pad, Install forms
- Set first segment of column
- Place footing reinforcing
- Cast footing concrete, Remove forms and backfill

WA I-5/US 12 Bridge: Fabrication & Construction



1) LOWER PIER CAP

2) GIRDERS ERECTED

3) UPPER-STAGE CAP CAST

Washington State
Department of Transportation

TRANTECH
Engineering LLC

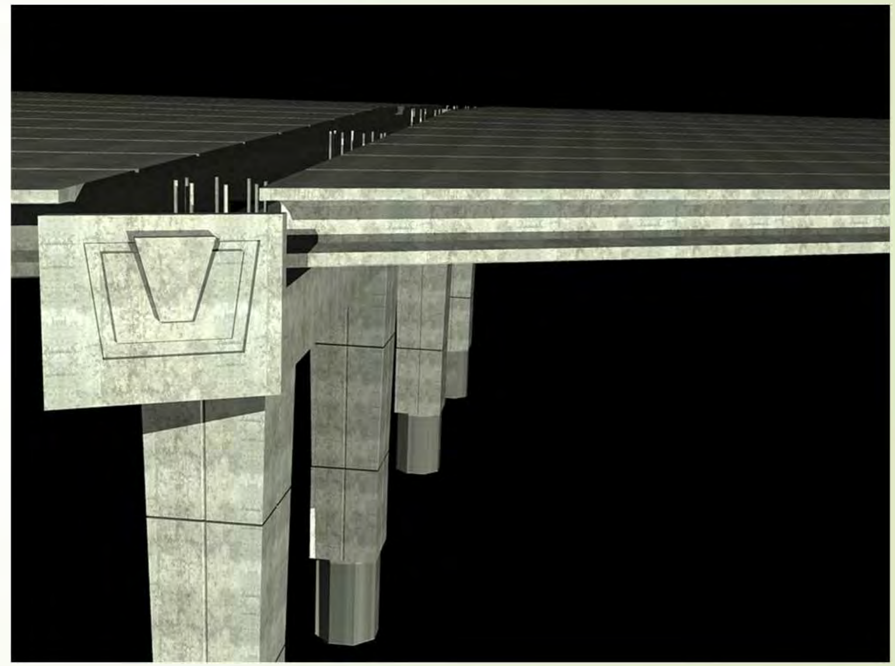
DBE
Certified

Bellevue
Bellingham
Pasco
Olympia

WA I-5/US 12 Bridge: Fabrication & Construction

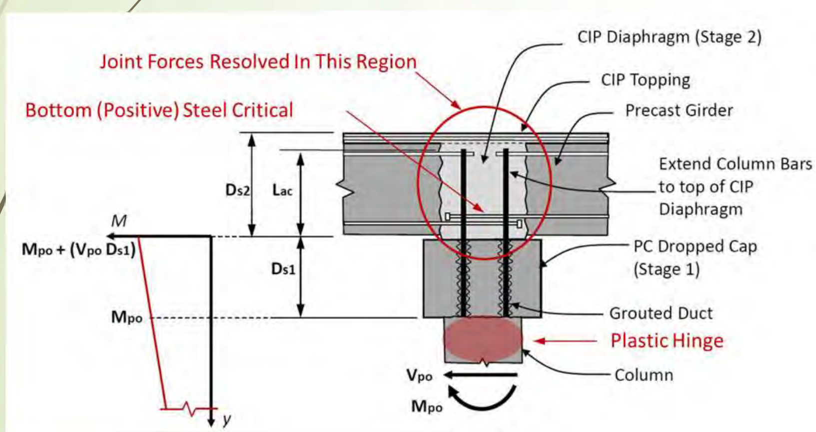
Prefabricated Concrete Products:

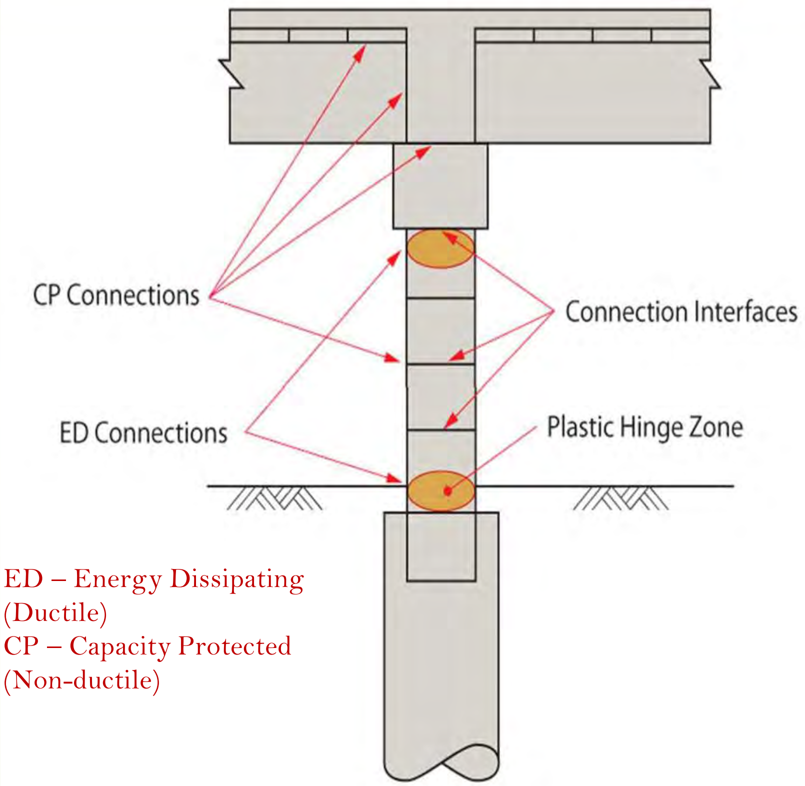
- 12 ea - Column Segments
- 2 ea - Crossbeams
- 30 ea – Decked Bulb Tee Girders
- 30 ea – End Walls
- 56 ea – Interior Diaphragms
- 2 ea – Cross Beam End Panels



Prefabricated Bridge Substructure Details

- Grouted Ducts
- Socket Connections
- CIP Bent Closure Joints
- Integral Substructure to Superstructure Connections

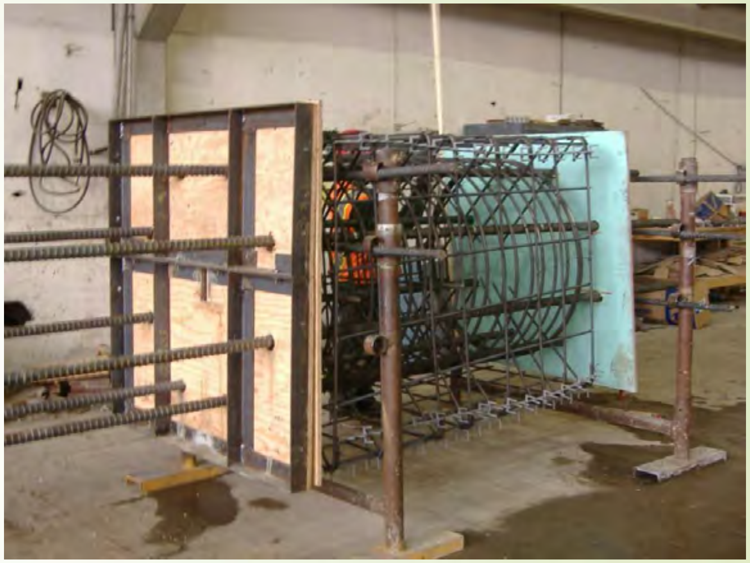




ED – Energy Dissipating (Ductile)
CP – Capacity Protected (Non-ductile)

WA I-5/US 12 Bridge: Fabrication & Construction

Bottom Column Segment



#14 HRC Headed Bars

Washington State Department of Transportation

TRANTECH Engineering LLC
DBE Certified
Bellevue
Bellingham
Pasco
Olympia

WA I-5/US 12 Bridge: Fabrication & Construction

Top Column Segment

Middle Column Segment

Construction: Column Sections Shipping and Handling

- Shipping Column Segments from CTC Fabrication Plant to the Jobsite
- Use Single Crane for Column Segments Placement

Washington State Department of Transportation

TRANTECH Engineering LLC

DBE Certified

Bellevue
Bellingham
Pasco
Olympia

Construction: Bottom Colum Section Placement

25 Kip Bottom Section

- Place Column Bottom Segments
- Place Footing Bars and Cast Footing
- Place Column Middle and Top Segments
- Use Shims for proper Erection

Placing the Column Through A Template

No Rebar Needed Through the Column Into the Footing

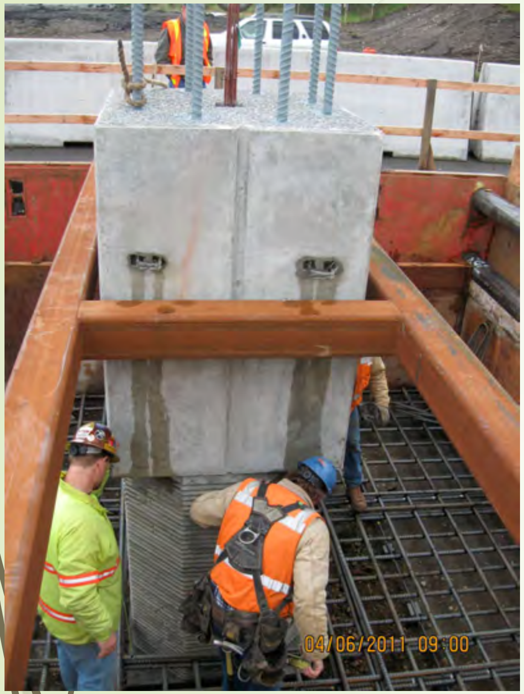
Washington State Department of Transportation

TRANTECH Engineering LLC

DBE Certified

Bellevue
Bellingham
Pasco
Olympia

Construction: Bottom Column Section Placement

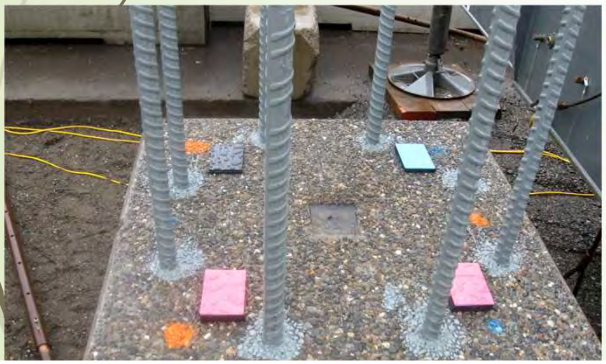


Photos. Construction sequence for placement of first precast column segment.

Washington State Department of Transportation

TRANTECH Engineering LLC · DBE Certified · Bellevue Bellingham Pasco Olympia

Construction: Column Sections Placement



Washington State Department of Transportation

TRANTECH Engineering LLC | DBE Certified | Bellevue Bellingham Pasco Olympia

Construction: Column Sections Erection

18 Kip Top Column Segment

Column Bracing

- Install bracing after Column Erection

Construction: Pretensioned Bent Cap Segments Placement

Photo: Erection of 53 ft Long Precast cap beam placement.

Washington State Department of Transportation

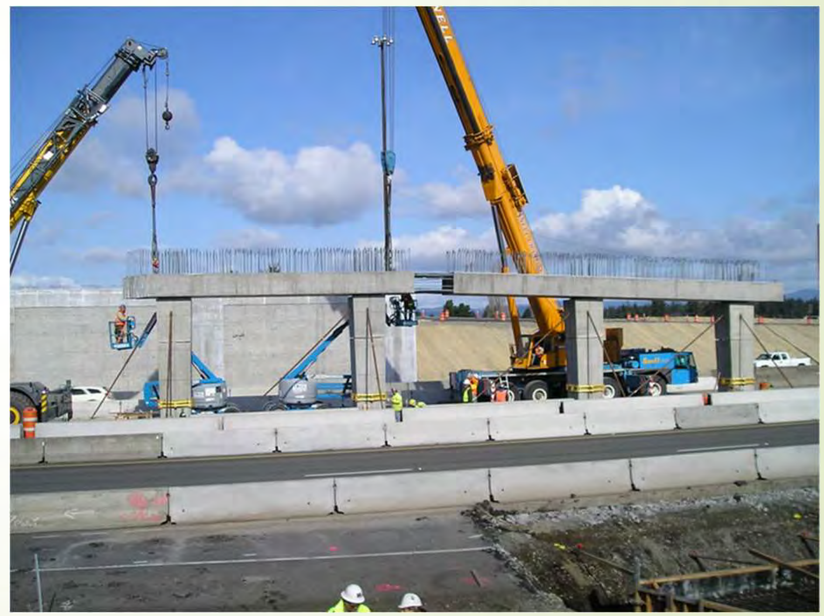
TRANTECH Engineering LLC

DBE CERTIFIED

Bellevue
Bellingham
Pasco
Olympia

Construction: Pretensioned Bent Cap Segments Placement

- Place Precast Pretensioned Bent Cap Segments – Two Cranes
- Column to Cap Grouted Duct Connections
- Cast CIP Concrete Closure Pours - 5.5 ft Long



Construction - Mock-up of the grouted joint

- Prior to erection of precast elements, several requirements were imposed on the contractor.
- To demonstrate capability to perform grouting operations through a mock-up of the grouted lap splice between column segments.
- Contractor successfully demonstrated this capability to adequately pump grout within the corrugated metal ducts without any voids.

Photo: Mock-up of the grouted joint.

Construction: Column Segments Grouting

Construction: Column Segments and Bet Cap Grouting

Grouting the Joints

- Install grout forms and seal
- Pump grout and close grout tubes
- Remove grout forms
- Inspect grout in joint and grout tubes
- Patch back grout tubes
- Investigate unfilled grout tubes
- Repair unfilled grout tubes

Photo. Grouting the joints between column segments and between columns and cap beam.

Construction Sequence for Placement of the Precast Superstructure

1. Place precast girders on oak blocks.
2. Install bracing and complete welded ties between girders.
3. Grout intermediate diaphragms and join flange shear keys.
4. Cast pier diaphragm concrete 10 days after slab casting.
5. Cast traffic barrier and sidewalk.

Module 2: ABC Substructure Grouted Ducts/Socket Connections in Washington State Bridge

1. Introduction
2. Design and Detailing
3. Fabrication and Construction
4. **Lesson Learned and Concluding Remarks**

Lessons Learned and Challenges Encountered

- Tolerance of precast pieces were not consistent with survey tolerances.
- Pressure from grouting may lift segments
- Shim locations and grout lifting pressures need to be included in erection plan calculations
- Grout form quality and ability to seal with column is key to successful grouting
- During inspection and grouting it would be helpful if grout tubes were as mapped as part of the precast operation.

CONCLUDING REMARKS

- **Goal of WSDOT HfL Project**- To bring emerging technology for ABC connections in two-stage cap beam bent construction in seismic regions was satisfied through this project.
- The project provides successful proof for design and construction of connections of a fully precast bent system meeting seismic design requirements.
- The project demonstrated a successful collaboration amongst a working group of DOT personnel, contractors, precasters, and researchers.

Washington State Department of Transportation, continues to look for opportunities to apply the technology, along with other methods, to accelerate bridge construction in the State.

Washington State Department of Transportation

TRANTECH Engineering LLC DBE Certified Bellevue Bellingham Pasco Olympia

Thank You

Amy Leland

LelandA@wsdot.wa.gov

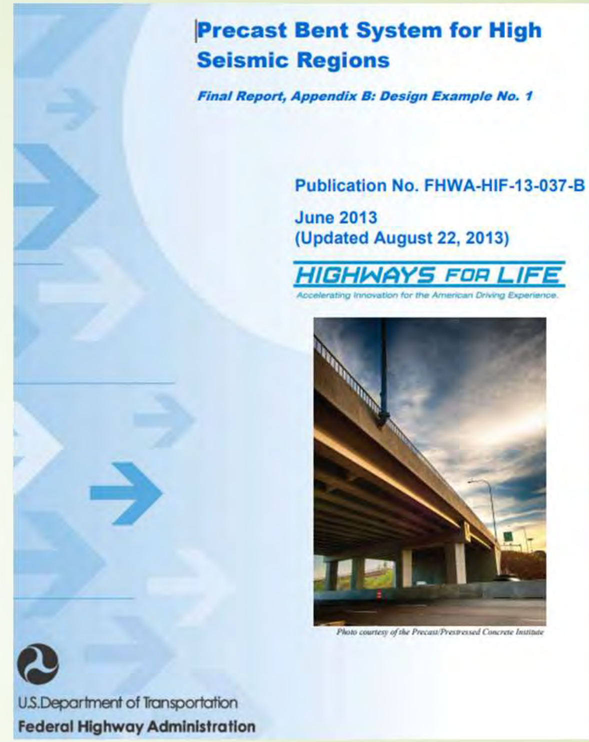
Khashayar Nikzad,

knikzad@trantecheng.com

Bijan Khaleghi,

Bkhaleghi@trantecheng.com

BKhalegh@fiu.edu


Precast Bent System for High Seismic Regions

Final Report, Appendix B: Design Example No. 1

Publication No. FHWA-HIF-13-037-B

June 2013

(Updated August 22, 2013)

HIGHWAYS FOR LIFE

Accelerating Innovation for the American Driving Experience.

Photo courtesy of the Precast/Prestressed Concrete Institute

U.S. Department of Transportation

Federal Highway Administration

Bijan Khaleghi, Eric Schultz, Stephen Seguirant, Lee Marsh, Olafur Haraldsson, Marc Eberhard, and John Stanton

Accelerated bridge construction in Washington State:

From research to practice

Washington State Department of Transportation

TRANTECH Engineering LLC

DBE Certified

Bellevue Bellingham Pasco Olympia