Western Bridge Engineer Seminar

New Development in Design and Construction of WSDOT Precast Concrete Bridges

Bijan Khaleghi
State Bridge Design Engineer

Washington State Department of Transportation
Bridge and Structures Office

Washington State Department of Transportation

WBES, Sacramento CA, September 22-24 2009

Outline

Precast Concrete Bridges

Innovative Designs

- LWC Girders
- SCC Girders
- Precast Curved Girders
- PT Precast Girders

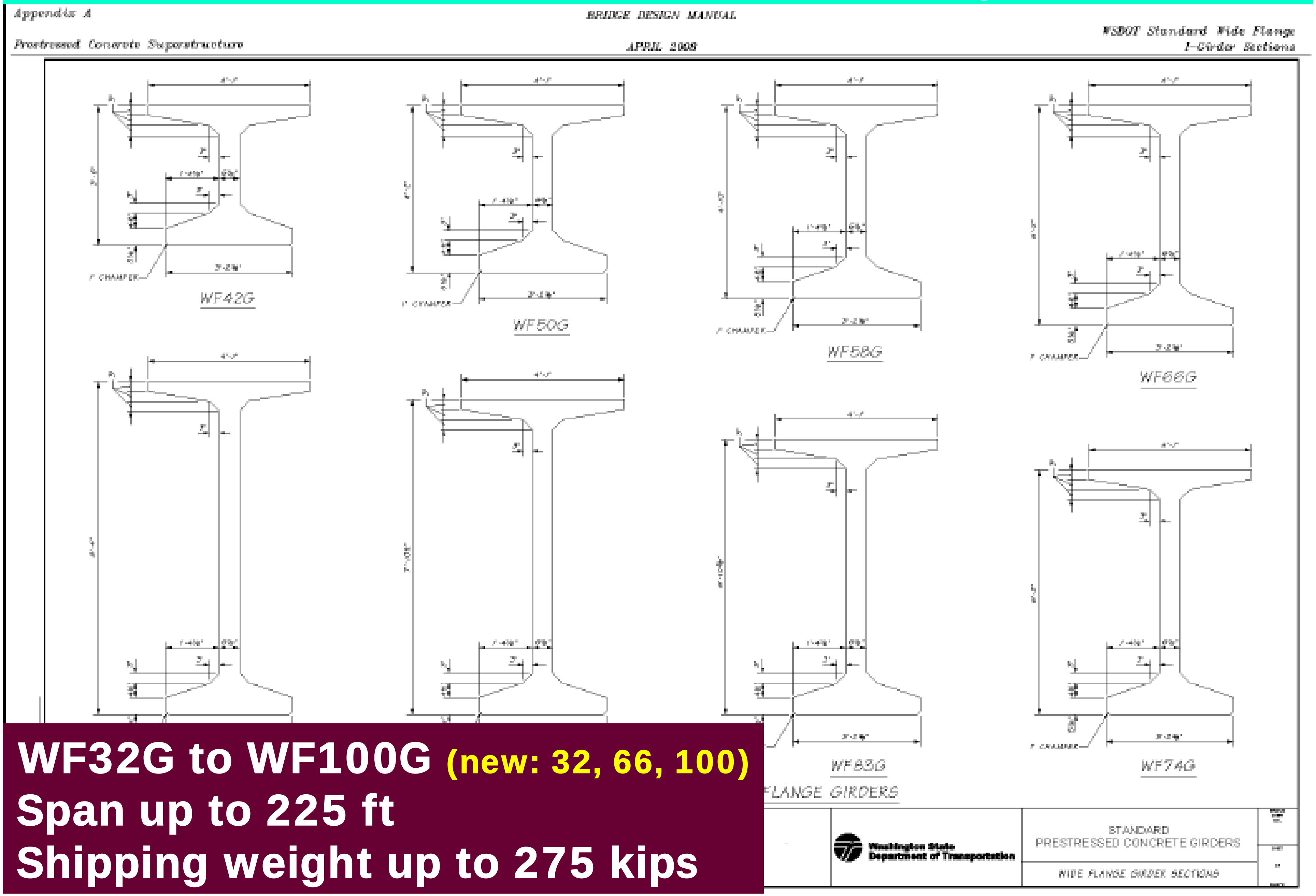
Precast Substructure

Advantages of Precast Concrete Bridges

- **Cost Effective**
- **Low life cycle costs**
- **Low Maintenance**
- **Availability of Precast Plants**
- **Longer spans with Precast Members**
- **Accelerated Construction**
- **Long-Term Performance**

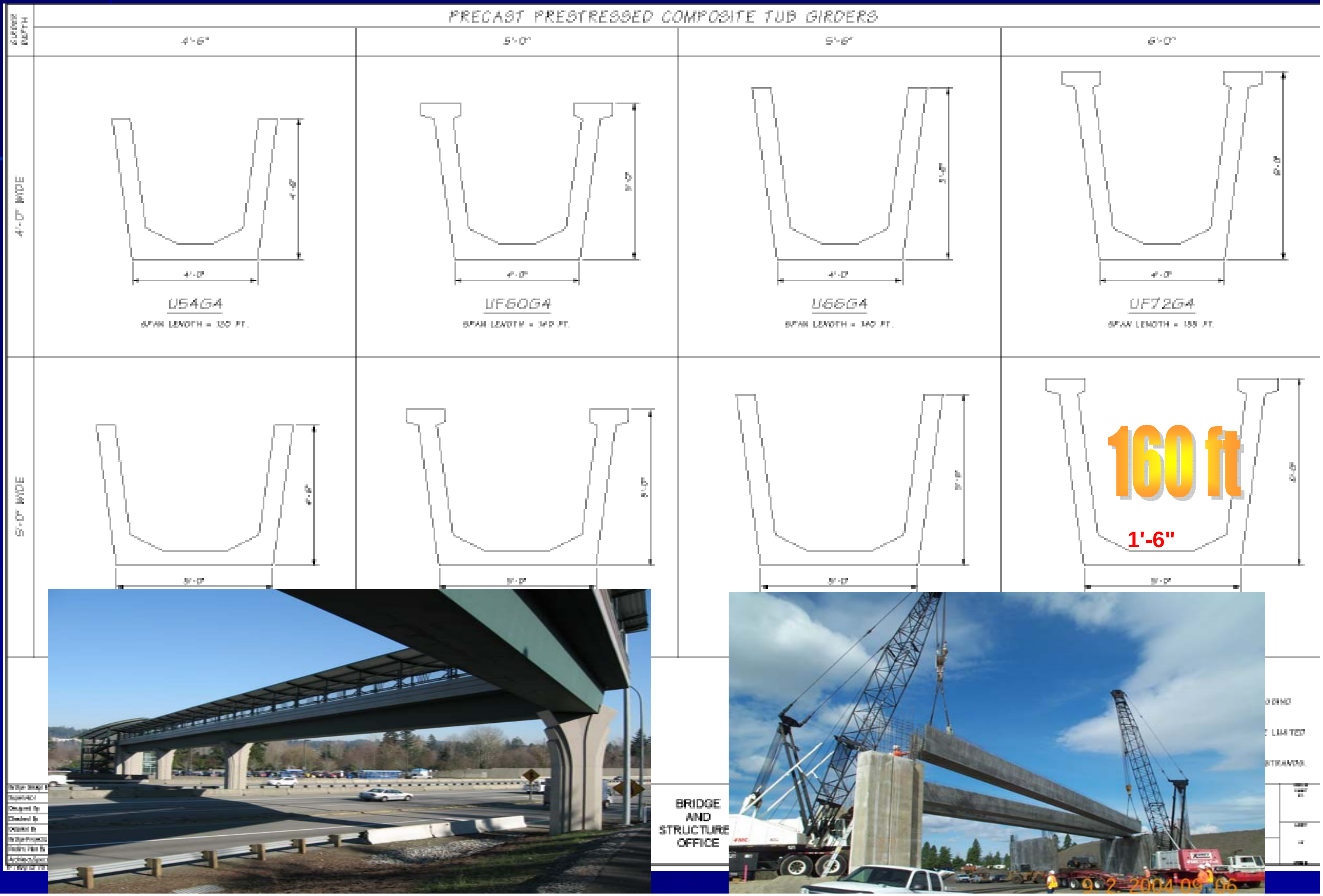
Year Built

Precast Pretensioned Wide Flange Girders



WF32G to WF100G (new: 32, 66, 100)
Span up to 225 ft
Shipping weight up to 275 kips

Precast Trapezoidal Tub Girders

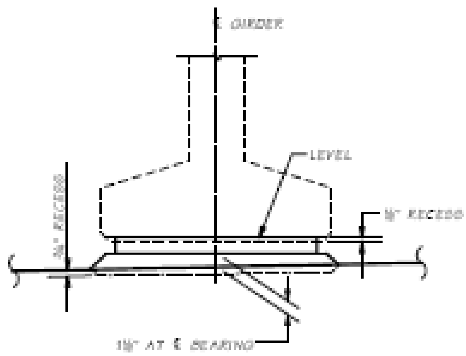


Long Span Precast Girders

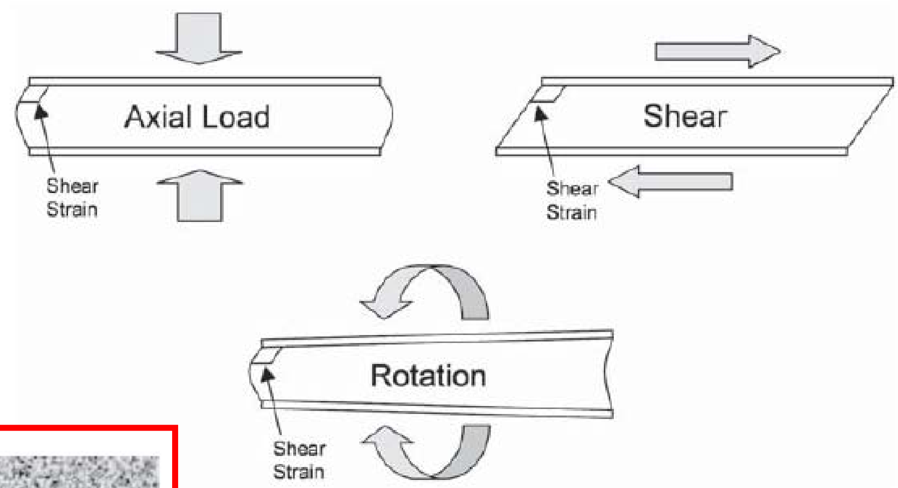
- Shipping and Handling
- Design for Shipping and Handling
- Girder Stability at Erection

Elastomeric Bearing for Long Span Precast Girders

- **Rotation:** Incorporate recommendations from NCHRP Project 12-68 Improved Rotational Limits of Elastomeric Bearings
- **Width Elastomeric Bearings > 20 in.**



GROUT PAD ELEVATION



Deformations of a laminated elastomeric bearing layer.

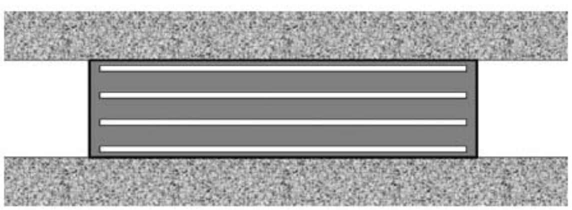


Figure 1.1. Cross-section of a steel-reinforced elastomeric bridge bearing.

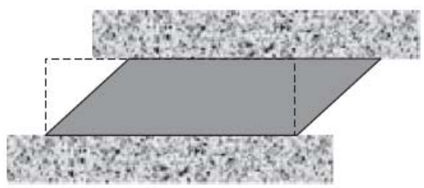
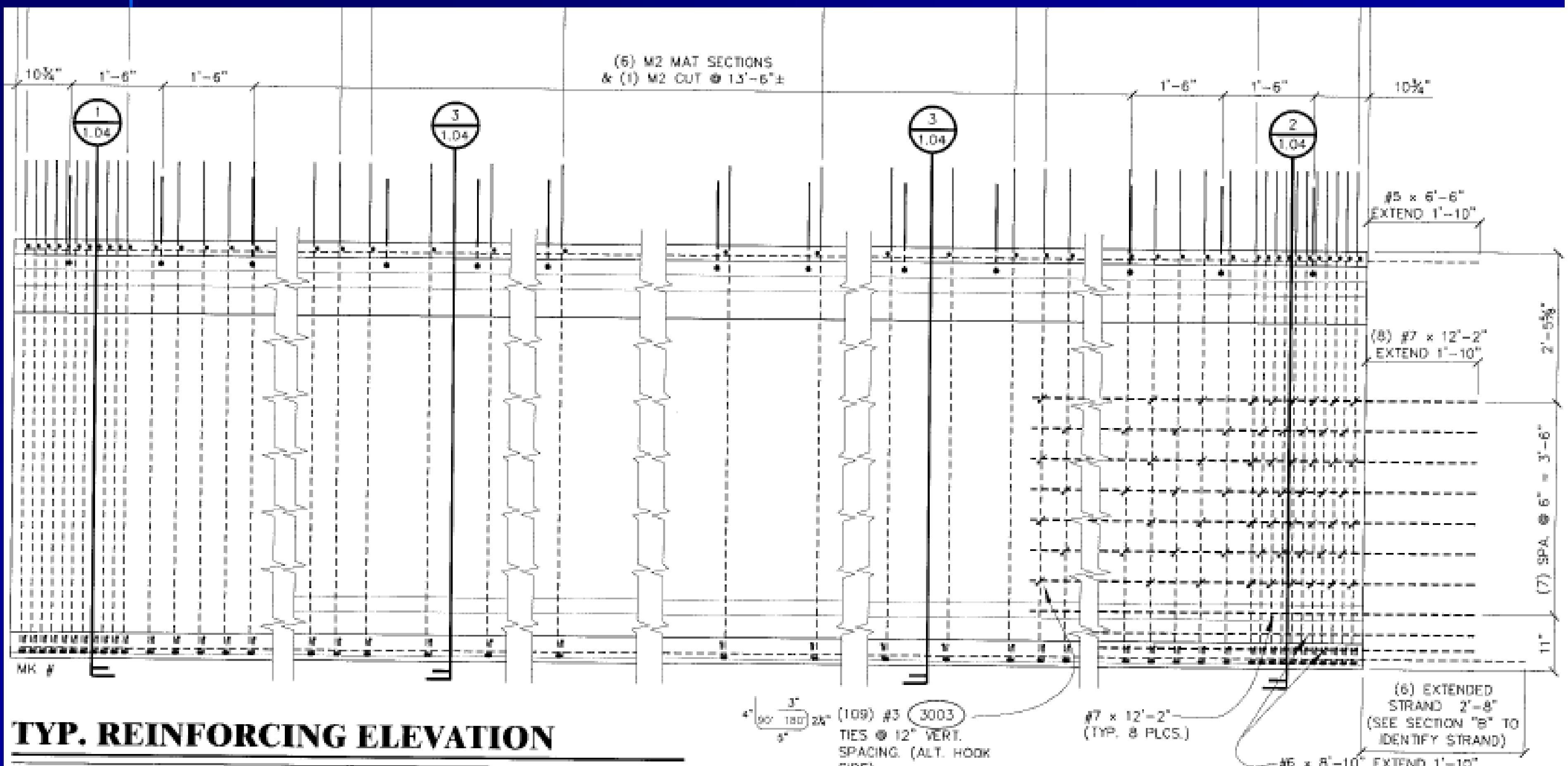


Figure 1.2. Elastomeric plain pad shearing to accommodate girder expansion.

WWF Reinforcement for Precast Girders

- One-on-one Replacement
- Grade 60 ksi (No Design Change)

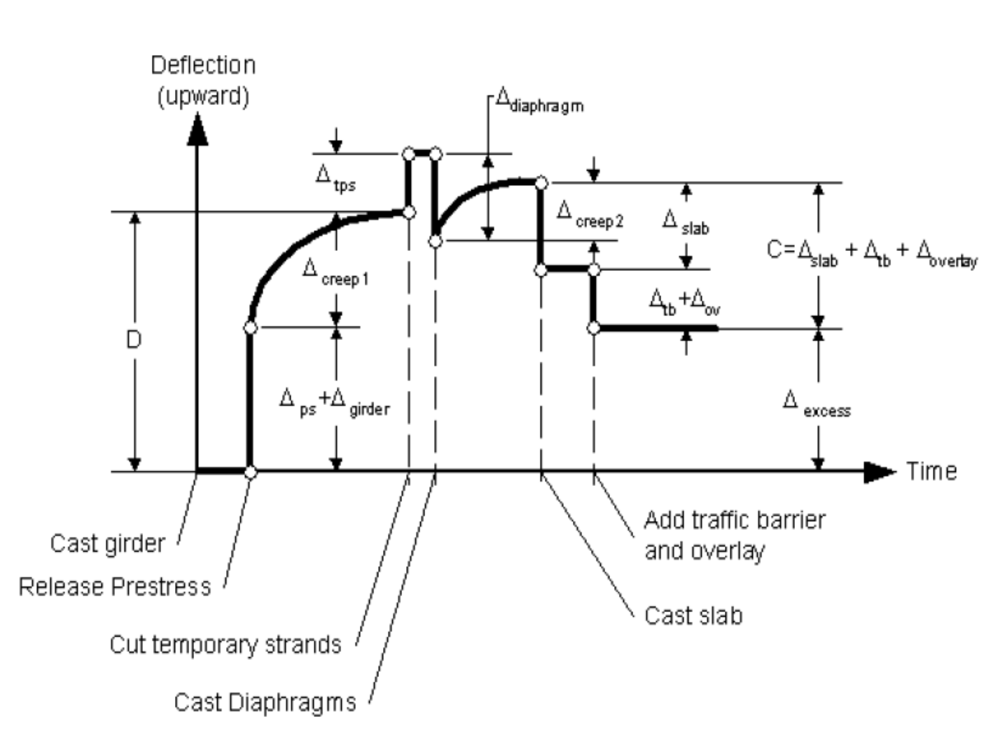


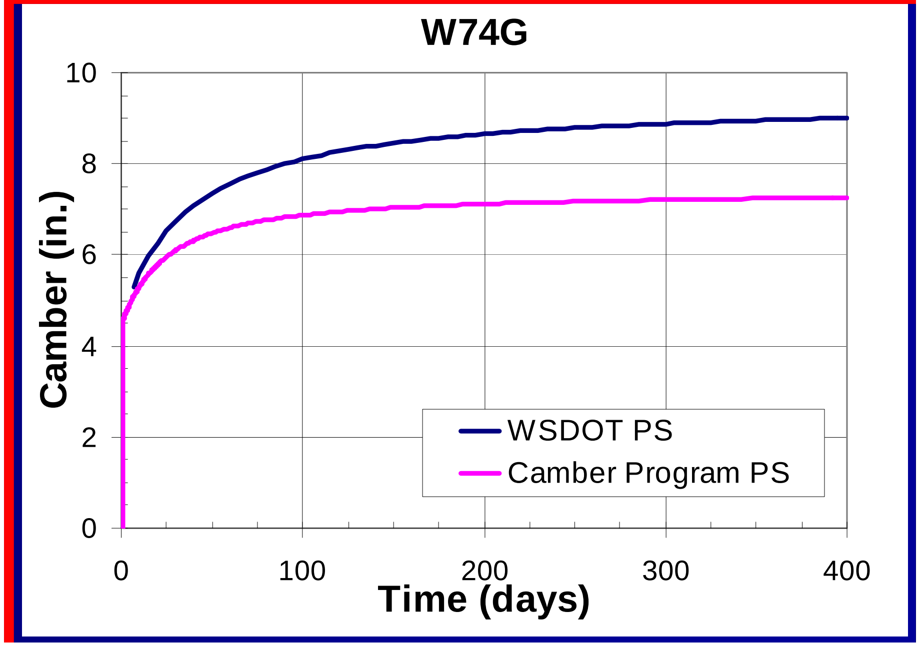
TYP. REINFORCING ELEVATION

Camber of Precast Girders

UW - Research Findings/Recommendations

- Include the prestress losses in camber calculations.
- Use adjusted strengths for camber design (Concrete Strength exceeds by 10% at release and 25% at 28-days)
- Use 15% higher Elastic Modulus than the AASHTO LRFD (recommended higher K_1 value for Washington aggregate).





Minimum Depth Limitations on Precast Slabs

Benefits: Shallow Depth superstructures

Concerns: Durability & Camber Variation

- Depth-to-Span Ratio > 0.03
- A minimum of 5 in. CIP topping

Standard Precast Prestressed Slab				
Precast Slab Designation	Max. Length (ft)	Depth (in.)	Nominal Width	Void Diameter (in.)
1'-0" - Solid Slab	33	12	4'-0"	N/A
1'-6" - Voided Slab	50	18	4'-0"	9
2'-2" - Voided Slab	72	26	4'-0"	16
2'-6" - Voided Slab	83	30	4'-4"	18
3'-0" - Voided Slab	100	36	5'-0"	22

Full Depth **Partial Depth**

Light Weight Aggregate Concrete Bridges

NCHRP 18-15 & FHWA LWC Project

Table 1: Aggregate Sources

Company	Agg. Type	Plant	Status
Big River Industries	Clay	Erwinville, LA	Received 2 pallets on 7/14 & 7/16
Carolina Stalite Company	Slate	Gold Hill, NC	Received 1 pallet on 10/5/08
Hydraulic Press Brick Co.	Shale	Brooklyn, IN	Received 2 pallets on 8/25
Northeast Solite Corp.	Shale	Saugerties, NY	Received 1 pallet (1600 lbs.) on 9/17
Texas Industries, Inc.	Clay	Frazier Park, CA	Received 1 pallet (3332 lbs.) on 8/22
Texas Industries, Inc.	Shale	Boulder, CO	Received 1 pallet (2180 lbs.) on 8/21

Table 13: Test Matrix for Lab Cast Beams

Concrete Strength (ksi) and Designation	Strand Size In.	Number of Beams	Measured Transfer Lengths	Flexural/Development Length Tests
8 – LWHPC 1	0.5	2	4	4
8 – LWHPC 2	0.5	2	4	4
10 – LWHPC 3	0.5	2	4	4
	0.6	2	4	4
8 – NWHPC 1	0.5	2	4	4
	0.6	2	4	4

Benefits of Light Weight Concrete:

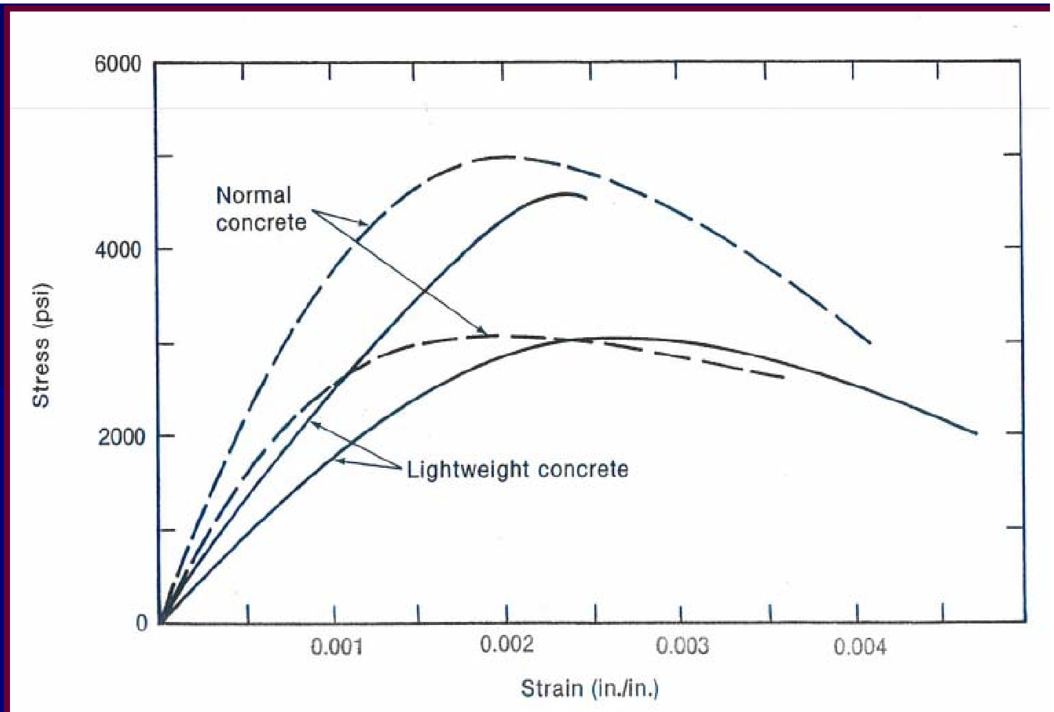
- Ease of Shipping and Handling
- Reduced Superstructure Mass
- Higher Ductility
- Better Fire Resistance

Concerns:

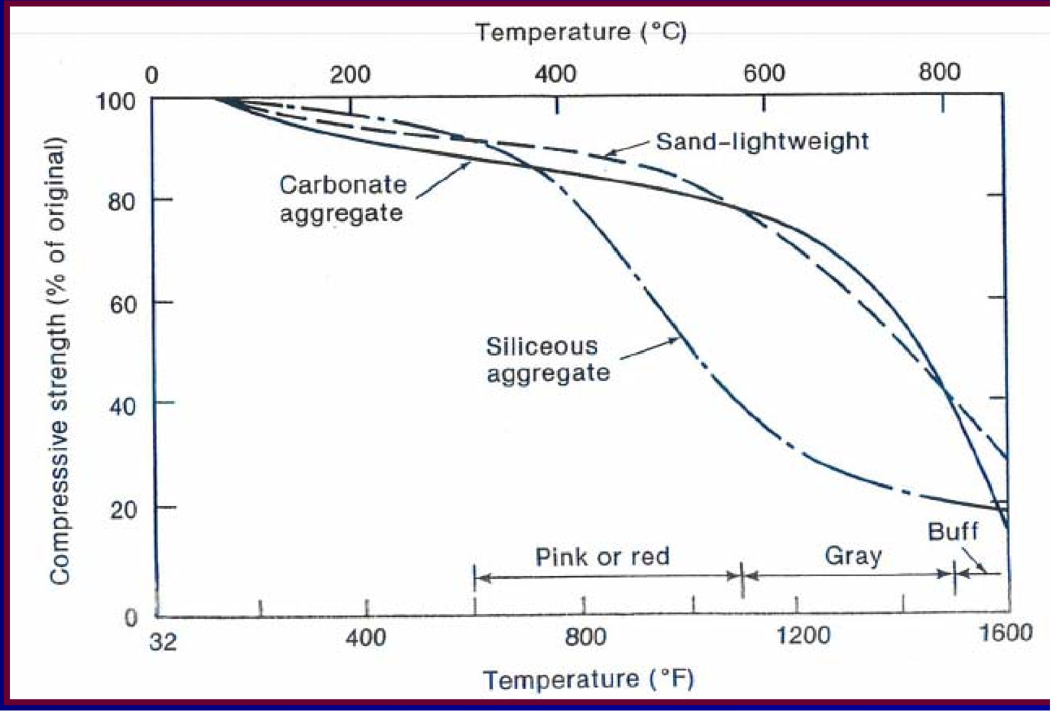
- Durability of Concrete
- Cost
- Availability

Benefits of LWC

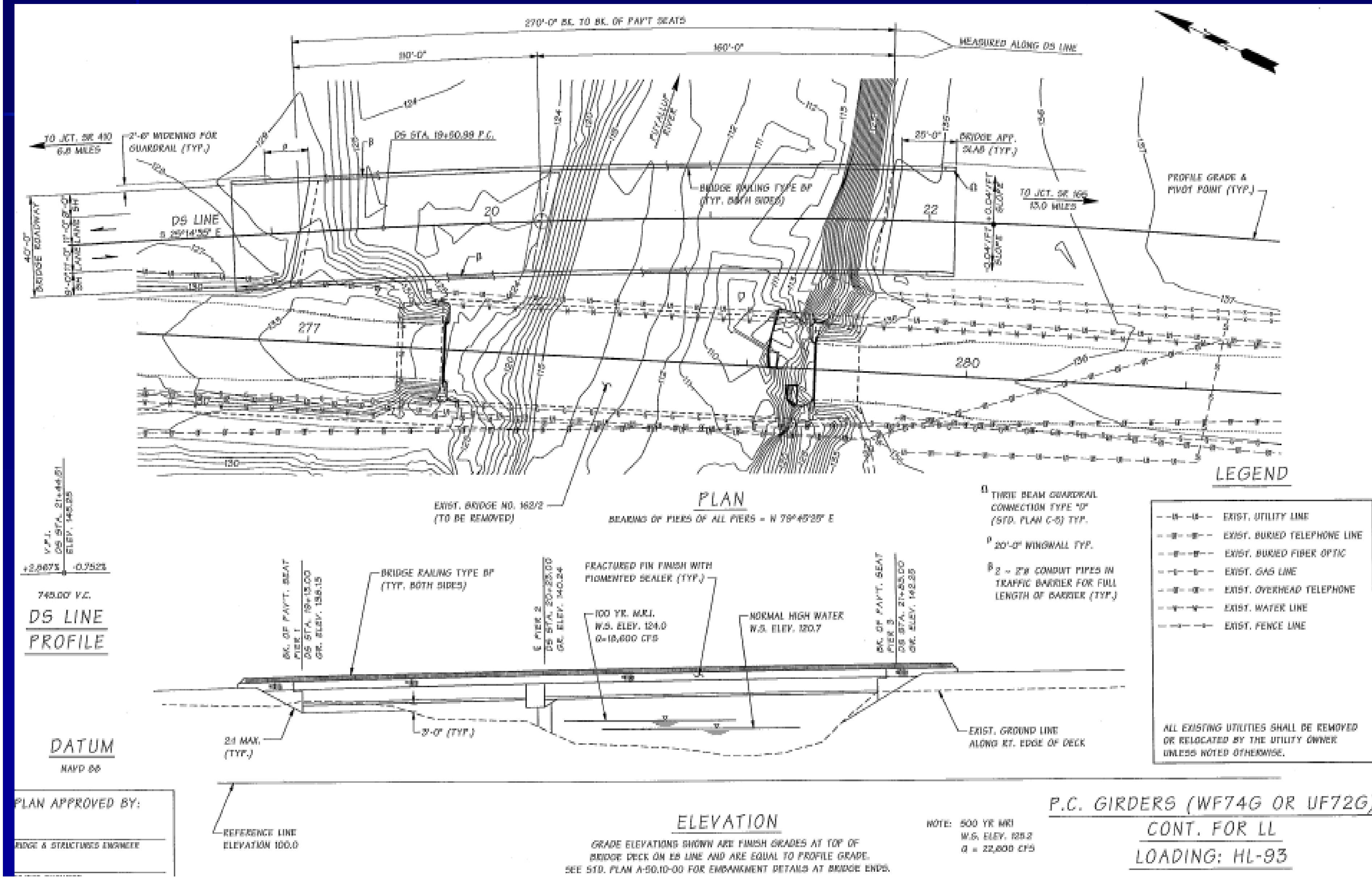
Compressive Stress-strain Curve Of Normal Weight And Light Weight Concrete (3ksi, 5ksi)



Compressive Strength Of Concrete At High Temperature

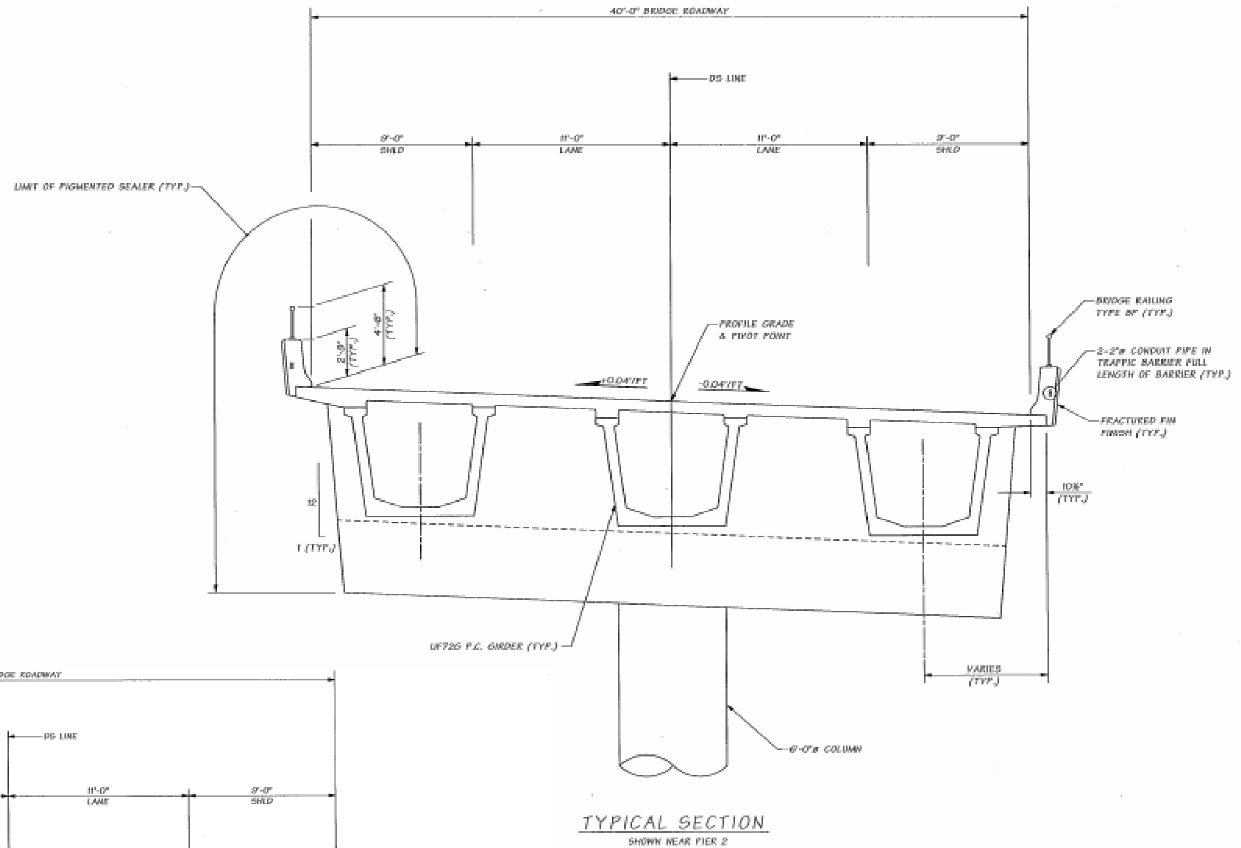


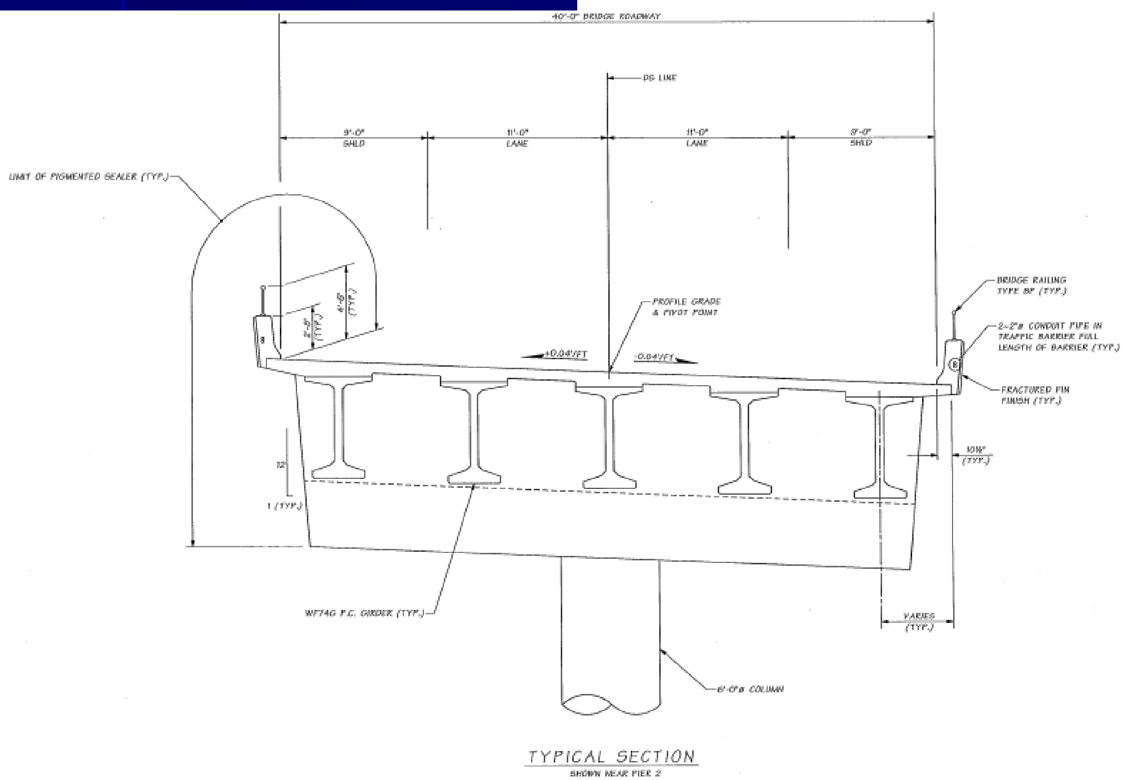
Light Weight Aggregate Precast Girder Bridge



Light Weight Aggregate Precast Girder Bridge

Case Study:
LWC Cost / Seismic





WF746:

Span = 160 ft

ω = 125 pcf

f'_{ci} = 7.0 ksi

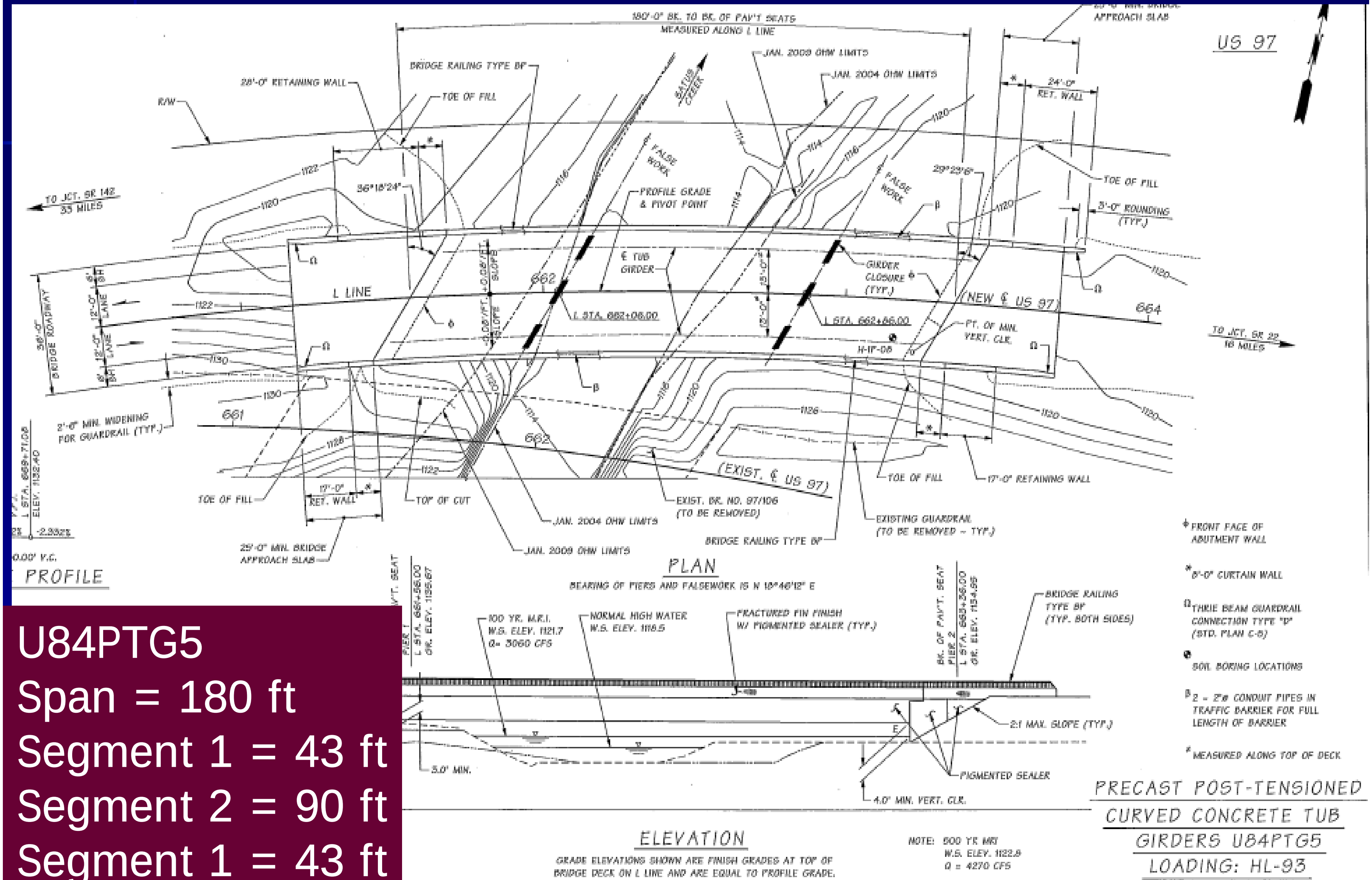
f'_{c} = 9.0 ksi

Precast Curved Girder Bridge

PCI Journal

Colorado flyover - Precast Curved Spliced girders for bridge project

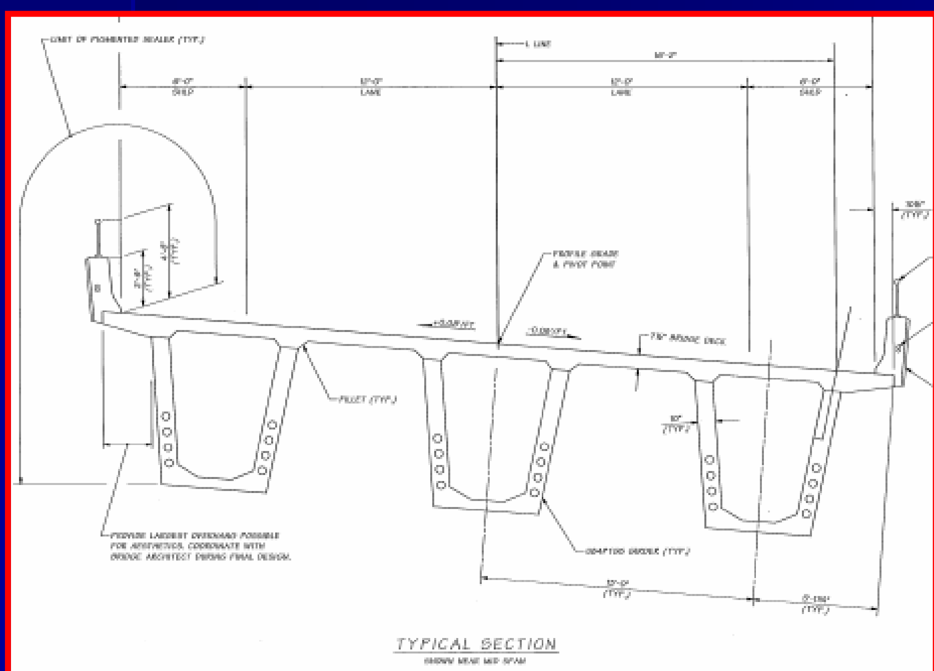
Precast Curved Girder Bridge



U84PTG5
Span = 180 ft
Segment 1 = 43 ft
Segment 2 = 90 ft
Segment 1 = 43 ft

Limitations for precast curved tub girders

- The overall width of segments < 16 ft.
- The shipping weight < 275 kips.
- A minimum web thickness of 10 in.
- in-plane & out-of-plane forces - 12-71
- Clear spacing between Ducts > 2.0 in.



Self Consolidated Concrete Girder Bridge

NCHRP REPORT 628
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

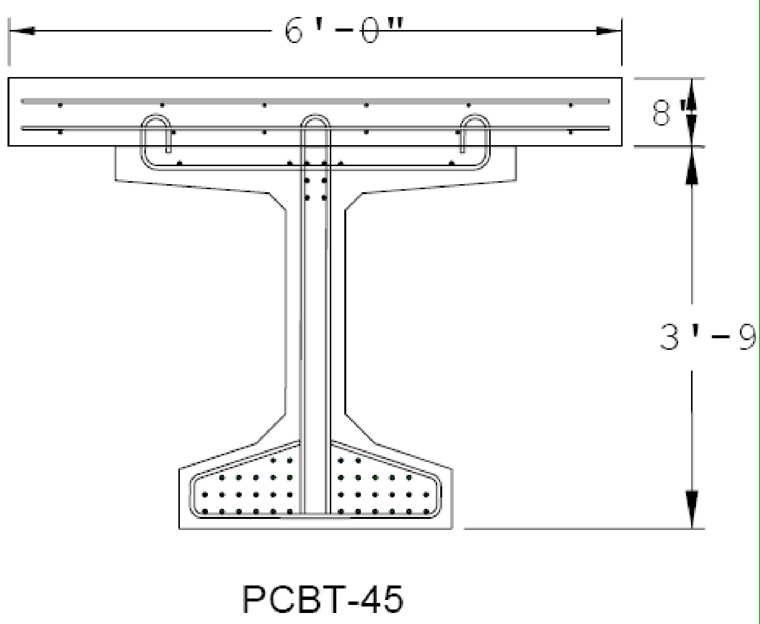


Figure 4. Cross Section of PCBT-45 Girder

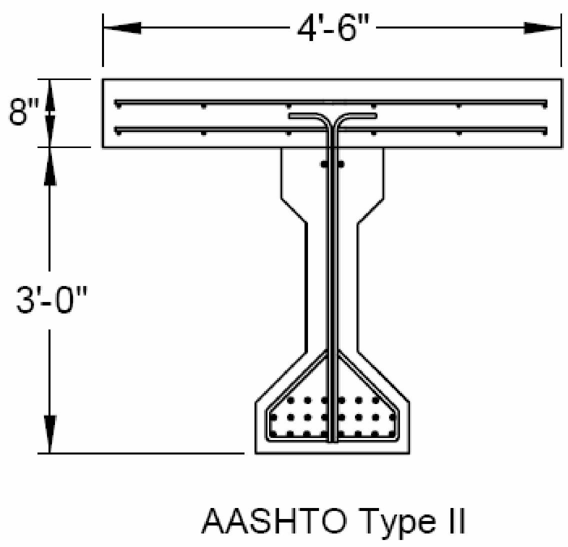


Figure 5. AASHTO Type II girder with cast-in-place deck

Self Consolidated Concrete Girder Bridge

B.1.2 Code provisions for mechanical and visco-elastic properties

Clause 5.4.2.3.2 Creep

The creep coefficient may be taken as:

$$\psi(t,t_i) = 3.5k_c k_f \left(1.58 - \frac{H}{120}\right) t_i^{-0.118} \frac{(t-t_i)^{0.6}}{10.0+(t-t_i)^{0.6}} \times A \qquad (5.4.2.3.2\text{-}1)$$

in which: $k_f = \dfrac{62}{42 + f_{ci}^{'}}$

where:

H = relative humidity (percent)

k_c = factor for the effect of the volume-to-surface ratio of the component

k_f = factor for the effect of concrete strength

t = maturity of concrete (day)

t_i = age of concrete when load is initially applied (day)

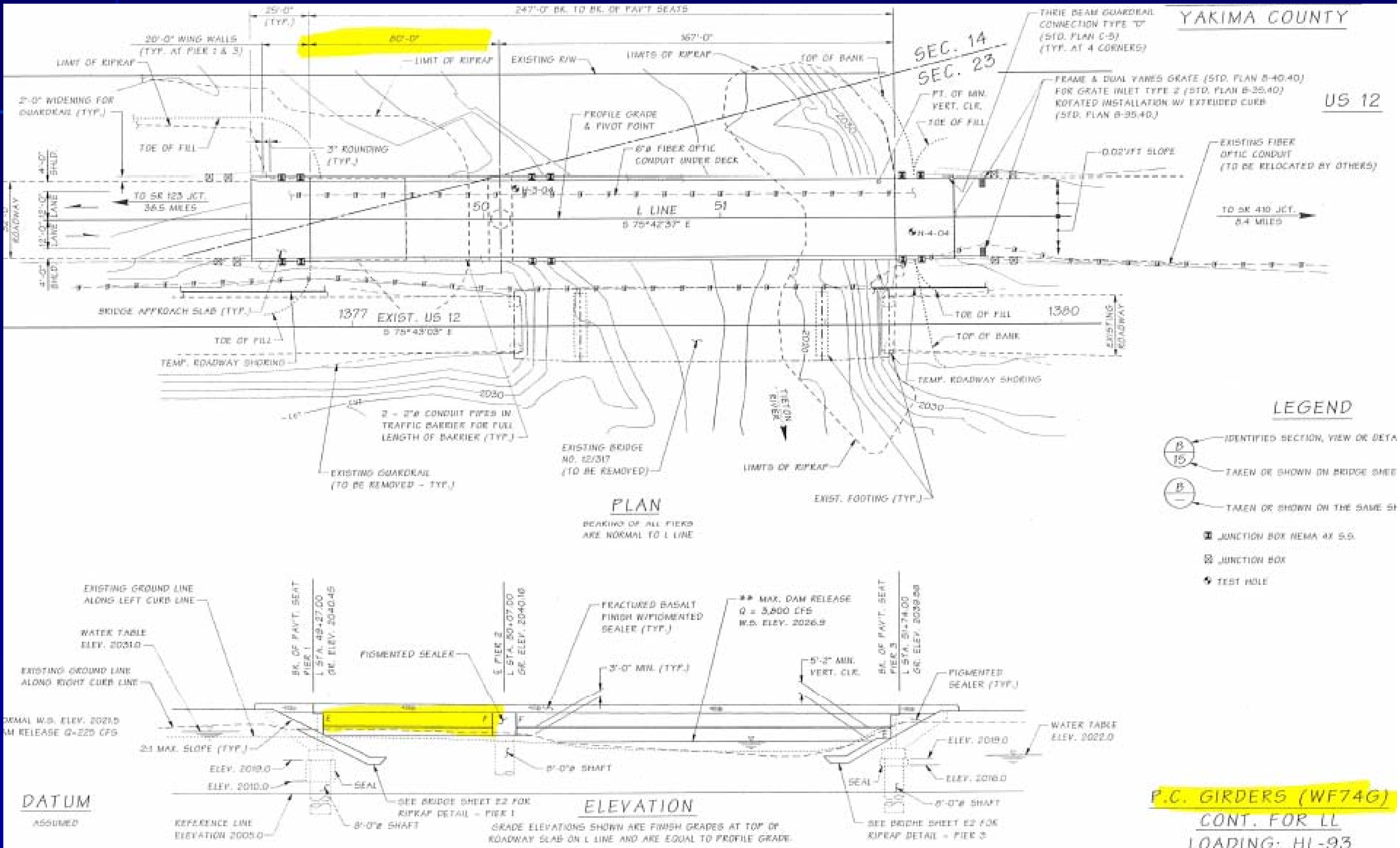
$f_{ci}^{'}$ = specified compressive strength at 28 days (MPa)

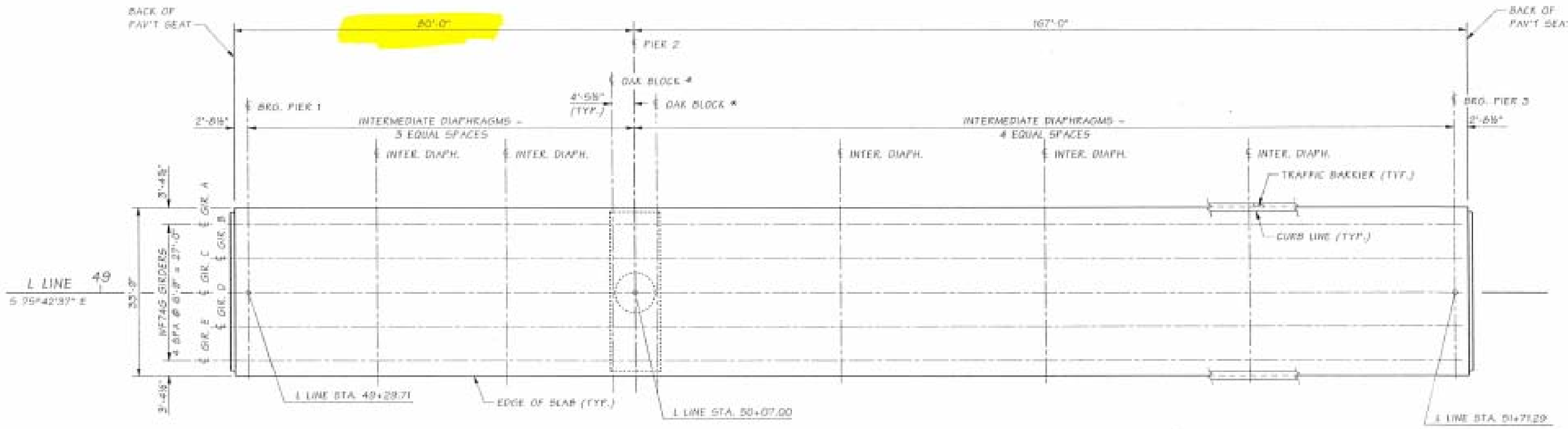
A = factor for the effect of cement type: 1.21 for Type I/II cement and 1.43 for Type III + 20 percent FA binder which may be used for P(SCC)

B.1.3 Structural behavior

More research is needed to quantify the influence of P(SCC) on the structural design parameters, such as loss of prestressing, camber, and shear resistance.

Self Consolidated Concrete Girder (IBRD)





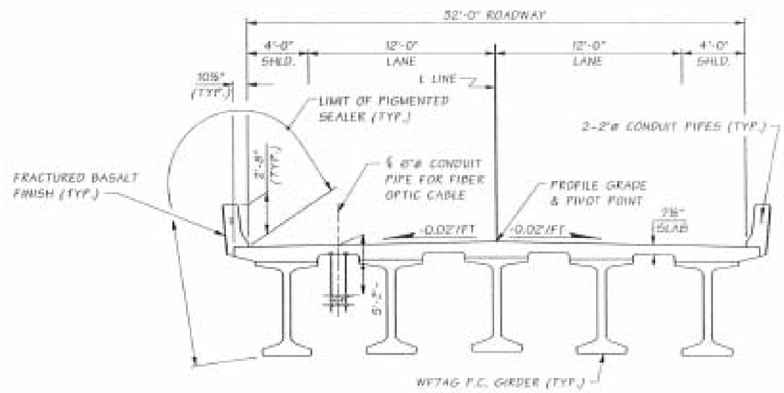
FRAMING PLAN

* SEE "OAK BLOCK DETAIL"

WF74G:

Span = 80, 167 ft

f'ci = 4.0 ksi
f'c = 5.0 ksi
C = 1/4 in.
D40 = 5/8 in.
D120 = 7/8 in.



TYPICAL SECTION

GIRDER SCHEDULE

DIMENSION "A" AT ℄ BEARINGS = 12"

BASED ON GIRDER DEFLECTION = "0" AT TIME OF SLAB PLACEMENT (120 DAYS)

SPAN	GIRDER	END 1 TYPE	END 2 TYPE	L	θ_1	θ_2	F_1	F_2	PLAN LENGTH (ALONG GIRDER GRADE)	MIN. CONC. COMPR. STRENGTH @ FINAL f'c (KSI)	MIN. CONC. COMPR. STRENGTH @ RELEASE f'ci (KSI)	HARPED NO. OF STRANDS	HARPED JACKING FORCE (KIPS)	STRAIGHT NO. OF STRANDS	STRAIGHT JACKING FORCE (KIPS)	TEMPORARY NO. OF STRANDS	TEMPORARY JACKING FORCE (KIPS)	LOCATION OF C.G. STRANDS (IN.) E	FE	Fb	Fo	C (IN.)	D 40 DAYS (IN.)	D 120 DAYS (IN.)	∆f (IN.)
1	A-E	A	D	1'-0"	90	90	1'-6½"	1'-2⅝"	75'-2"	6.0**	4.0**	3	151.65	12	527.31	0	0	2.67	3.0	3.00	27.67	0.23	0.68	0.85	N/A
2	A-E	D	A	8'-0"	90	90	1'-2⅝"	1'-6½"	162'-2"	9.4	7.7	18	790.97	42	1845.58	4	175.77	3.71	4.0	3.00	12.0	3.48	5.02	5.67	N/A

New NCHRP Research Proposal (CIP-SCC)

Self-Consolidating Concrete for Cast-in-place Concrete Bridges

- Develop guidelines for the use of self-consolidating concrete in ready-mixed cast-in-place concrete in highway bridges
- Recommend relevant changes to the AASHTO LRFD Bridge Design and Construction Specifications

Structural Concretes:

- Min. Prescriptive Concrete Mixes

Table C5.4.2.1-1 Con[illegible]te Mix Characteristics By Class.

Class of Concrete	Minimum Cement Content	Maximum W/C Ratio	Air Content Range	Coarse Aggregate Per AASHTO M 43 (ASTM D 448)	28-Day Compressive Strength
	pcy	lbs. Per lbs.	%	Square Size of Openings (in.)	ksi
A	611	0.49	—	1.0 to No. 4	4.0
A(AE)	611	0.45	6.0 ± 1.5	1.0 to No. 4	4.0
B	517	0.58	—	2.0 to No. 3 and No. 3 to No. 4	2.4
B(AE)	517	0.55	5.0 ± 1.5	2.0 to No. 3 and No. 3 to No. 4	2.4
C	658	0.49	—	0.5 to No. 4	4.0
C(AE)	658	0.45	7.0 ± 1.5	0.5 to No. 4	4.0
P P(HPC)	564	0.49	As specified elsewhere	1.0 to No. 4 or 0.75 to No. 4	As specified elsewhere
S	658	0.58	—	1.0 to No. 4	—
Lightweight	564	As specified in the contract documents			

Survey: AASHTO, TRB and Concrete Industries

- **Prescriptive Concrete Mixes**
- **Performance Based Concrete Mixes (Pilot)**
- ***Partially Performance/Prescriptive Mixes***

(Min. Prescriptive + Performance)

Performance Requirements:

Strength (T 22),
Modulus (C 469),
Creep (C 512),
Early Shrinkage (T 160)
Permeability (T 277),
Scaling (C 672),
Freeze Thaw (T 161),
Abrasion (C 944), ASR (T 303)

Pilot Projects in different Geographic Regions of Washington State

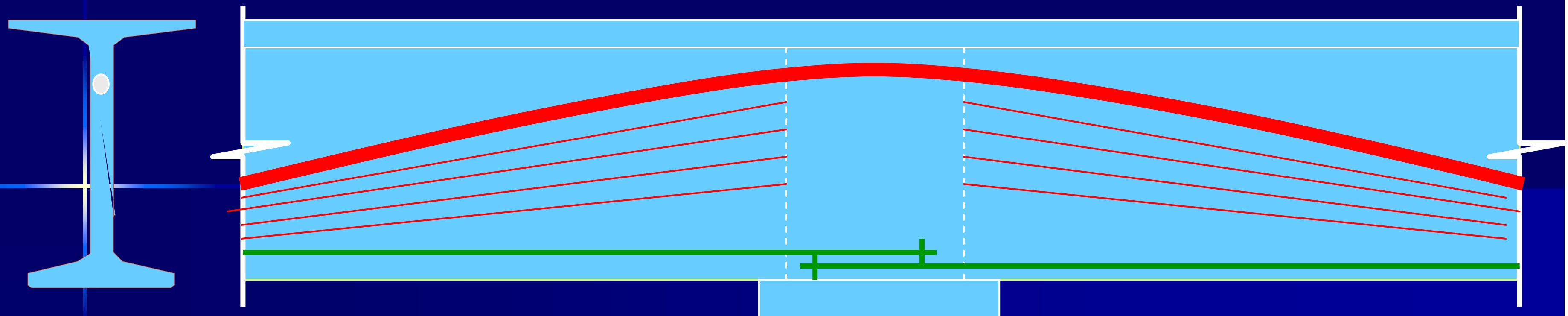
New Research Proposal

- **Investigate Suitability of Performance based mixes for Structural Concretes**
- **Investigate acceptable range of variability in concrete mix ingredients**
- **Investigate Structural Properties of performance based Concretes for E, CR, SH, f_r, Bond, Shear and Flexural Resistance, etc.**
- **Investigate Durability of Concretes made with undefined mix designs**
- ***<u>Propose Range of Mix Designs Suitable For Structural Concretes</u>***

Bridge Deck Cracking:

- Require PT for all CIP Superstructures (M^+ & M^-)
- Recommend PT for Continuous Precast Girder Bridges

Precast PT I-Girders – Continuous Bridges



PT for Continuity:

Benefits: Design for Continuous Superstructure
Durable Deck Slab **Design for Zero Tension**

Concerns: Increased Construction Cost - PT
Increased Shipping and Handling Cost
Increased Mass - Seismic

Stay-in-place Deck Panels

- **Benefits: Accelerates Bridge Construction**
- **Concerns: Long Term Durability - Longitudinal and Transverse Deck Cracking due to Stiffness and Shrinkage**

Stay-in-place Deck Panels

The conventional full-depth C-I-P slab continuous to be preferred for most applications.

1. S-I-P Deck Panels shall not be used in Negative moment region of continuous bridges.
2. S-I-P Deck Panels may be used in post-tensioned continuous bridges.
3. S-I-P Deck Panels shall not be used in Bridge widening and Phased construction in the bay adjacent to the existing Structures
4. A min. slab thickness of 8.5″, including 3.5″ precast deck panel and 5″ C-I-P topping shall be specified.
5. S-I-P Deck Panels are not allowed for steel bridges.

Precast Substructure

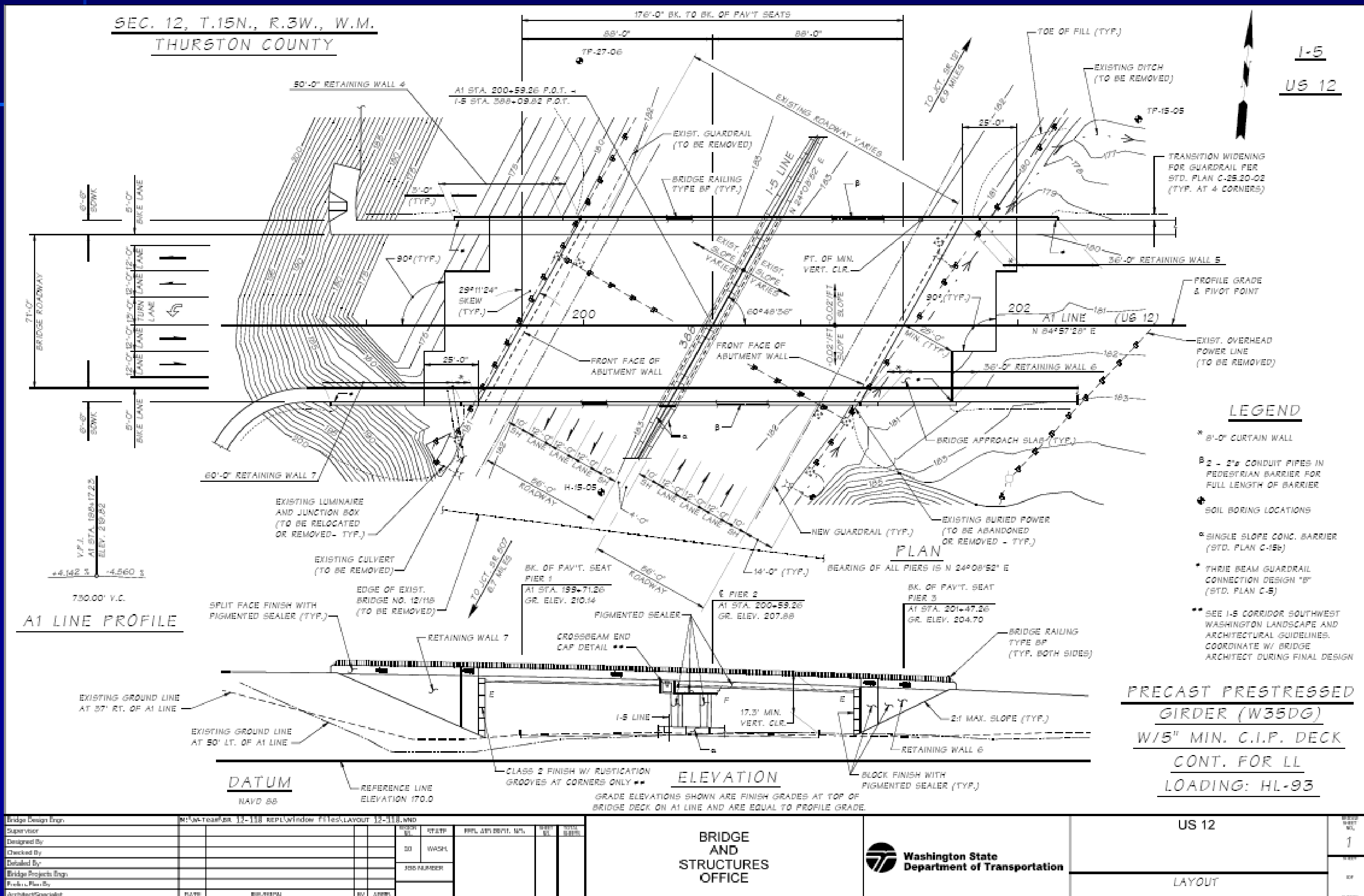
- **Benefits:** Accelerated Bridge Construction
- **Concerns:** Seismic Performance
  Durability of Connections

Current Practice: Cast-in-place Emulative Connections

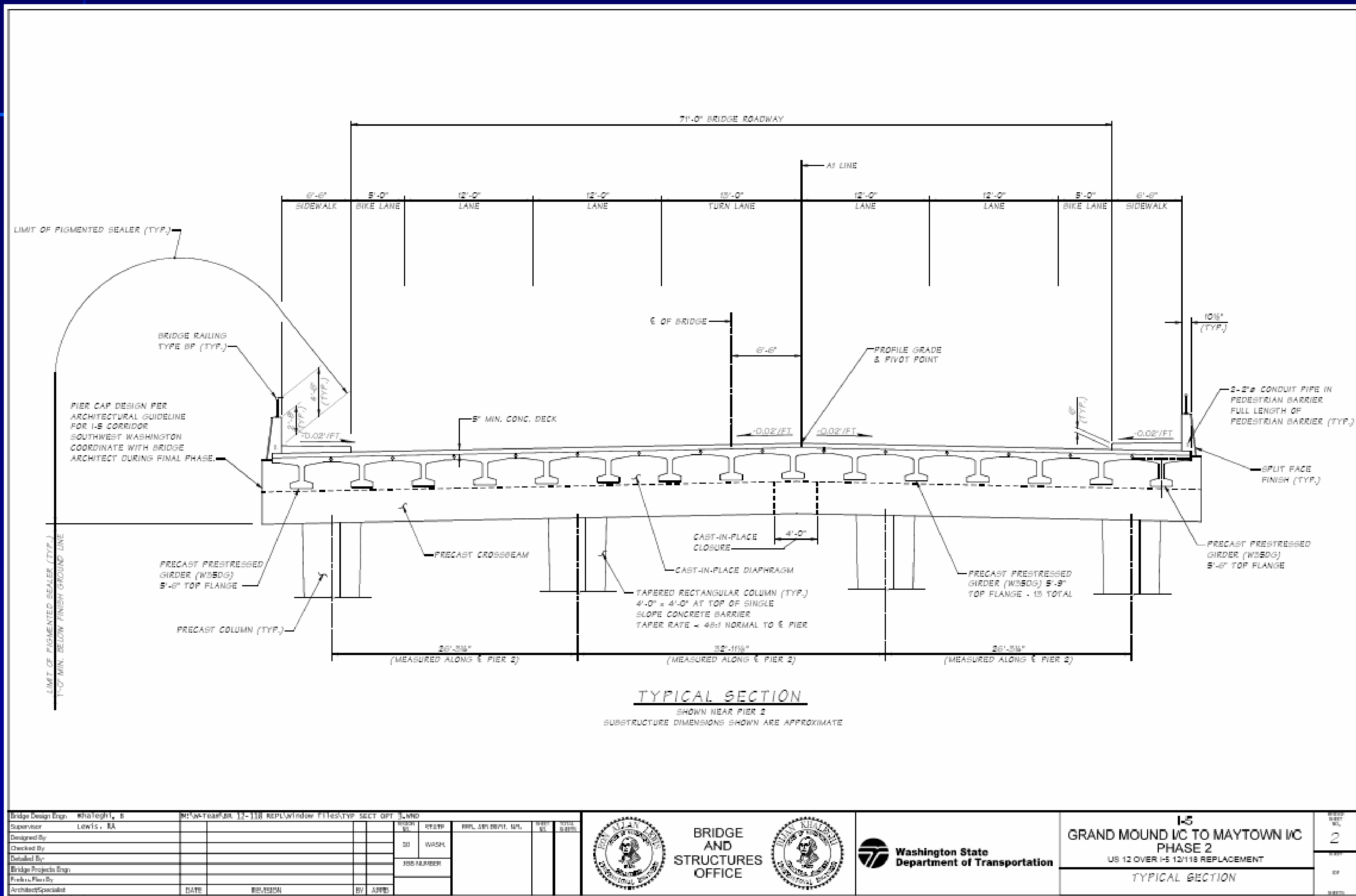
Precast Substructure

- **Benefits:** Accelerated Bridge Construction
- **Concerns:** Seismic Performance
  Durability of Connections
  Construction Cost

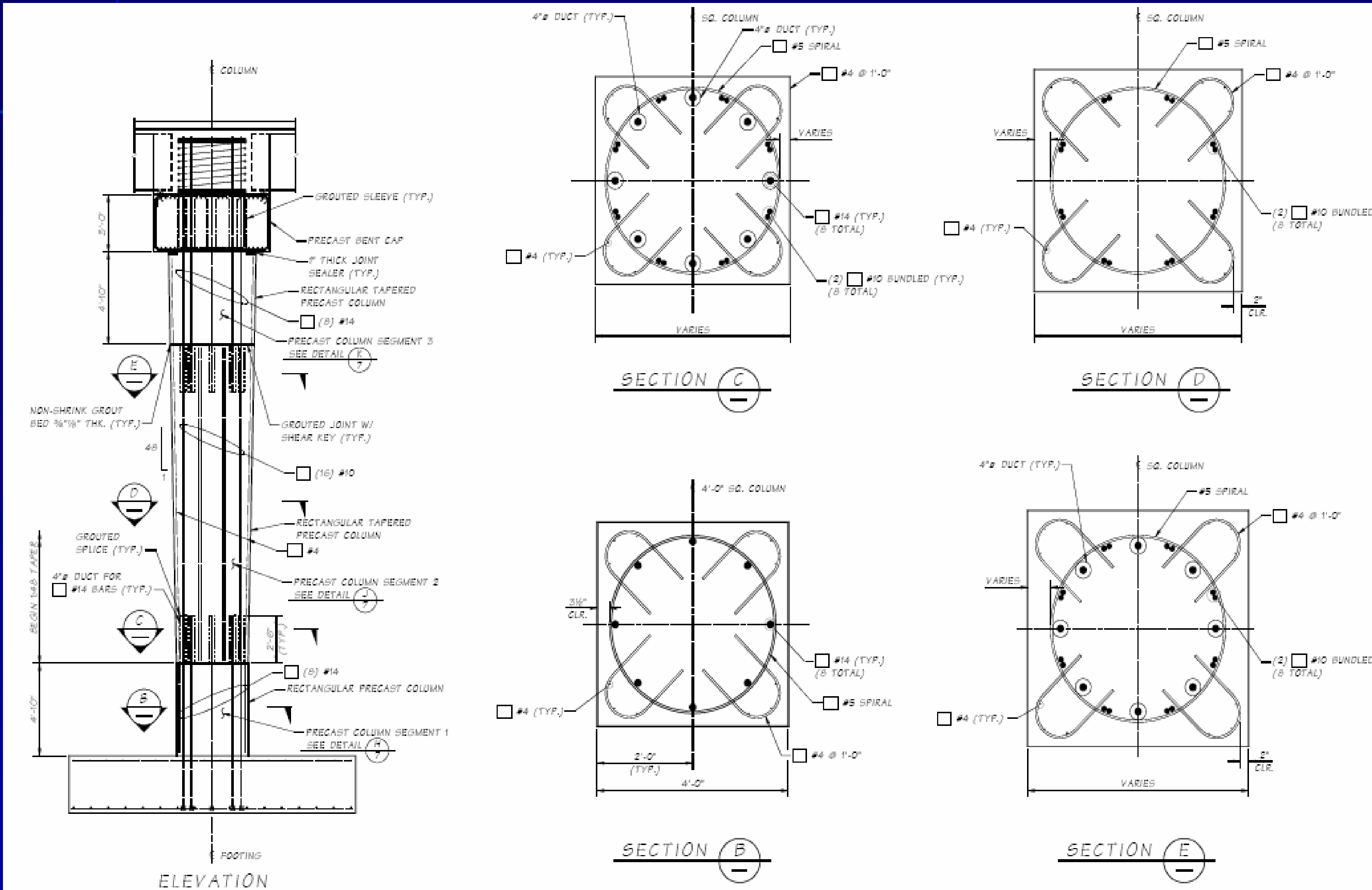
FHWA Highways for LIFE – HFL Project
Fully Precast Bridge in Seismic Regions



FHWA Highways for LIFE – HFL Project
Fully Precast Bridge in Seismic Regions



FHWA Highways for LIFE – HFL Project Fully Precast Bridge in Seismic Regions



Thank you

WSDOT Bridge:
http://www.wsdot.wa.gov/eesc/bridge/index.cfm/

BDM:
http://www.wsdot.wa.gov/eesc/bridge/bdm/

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

Bridge STD Drawings:
http://www.wsdot.wa.gov/eesc/bridge/drawings/

khalegb@wsdot.wa.gov
(360) 705-7181