PCI Spliced Curved U Girders
Bob Anderson and William Nickas

Outline

1. Industry Partners and Tools
2. Who is NCBC
3. Curved Spliced U Girders
4. First Zone 6 U Beams and CFX
5. Future efforts by PCI

Outline

1. **Industry Partners and Tools**
2. **Who is NCBC**
3. **Curved Spliced U Girders**
4. **Dura-Stress and the first Zone 6 U Beams**
5. **Future efforts by PCI**

Innovative Solutions for tomorrow's transportation needs

Industry Partners and Tools

- Knowledge Creation
  - Industry Committees and vetting research
  - Manuals and Standards Development
- Knowledge Dissemination
  - Past Successes and lessons learned
  - Showcases
  - Training
- Continuous Improvement
  - Quality Programs and Continuous Improvement
  - Shape future thru Research

Innovative Solutions for tomorrow's transportation needs

AISC / PCI (2009)

- White Paper expands on AASHTO Resolution
- Set forth 12 essential elements of a comprehensive Quality Program

Please help your Industry partners educate all professionals…..

Each of you here are asked to educate your leadership that a creditable certification has a "chain of custody arrangement" back to fundamental "body of knowledge" to facilitate consistent interpretation/deployment and continuous improvement.

A checklist is just not good enough.

7

National Concrete Bridge Council

- American Coal Ash Association
- American Segmental Bridge Institute
- Concrete Reinforcing Steel Institute
- Expanded Shale, Clay, and Slate Institute
- National Ready Mixed Concrete Association
- Portland Cement Association
- Precast/Prestressed Concrete Institute
- Post-Tensioning Institute
- Slag Cement Association
- Silica Fume Association
- Wire Reinforcement Institute

8

Industry Plant and Personnel Certification Programs

Past Curved PreTensioned Concrete

Curved Spliced U Girders

Game changer

PCI
Innovative Solutions for tomorrow's transportation needs

Superstructures

Latest Trailers Maximum Capacity 340,000 lbs

PCI

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Superstructures

Wheels Expand to 19 feet wide

PCI

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PCI Zone 6 Standards

- Southeast details are different thus the PCI Zone 6 standards
- Present Optional Details
- Robust Post-Tensioning systems required in corrosive climates
- Further Customized for FDOT adoption with FHWA Approval

PCI Zone 6 U Beam Go By Sheets

INDEX OF DRAWINGS

U-1	GENERAL INFORMATION
U-2	TYPICAL BRIDGE CROSS SECTIONS
U-3	TYPICAL BRIDGE CROSS SECTION WITH PRECAST PANELS
U-4	MAXIMUM DESIGN SPANS – THREE SPAN CONSTANT DEPTH GIRDERS
U-5	MAXIMUM DESIGN SPANS – SIMPLE SPAN CONSTANT DEPTH GIRDERS
U-6	MAXIMUM DESIGN SPANS – THREE SPAN HAUNCHED GIRDERS
U-7	GIRDER DIMENSIONS & REINFORCEMENT
U-8	GIRDER END AND SLICE DETAILS
U-9	TYPICAL THREE SPAN CONSTANT DEPTH GIRDERS
U-10	END DIAPHRAGM AT ABUTMENT
U-11	TYPICAL EXPANSION PIER
U-12	TYPICAL INTERIOR PIER WITH BEARINGS
U-13	TYPICAL INTEGRAL INTERIOR PIER
U-14	PRECAST PANEL DETAILS
U-15	BOTTOM SLAB ACCESS HATCH
U-16	CONSTANT DEPTH GIRDER CONSTRUCTION SEQUENCE
U-17	SIMPLE SPAN CONSTANT DEPTH GIRDER CONSTRUCTION SEQUENCE
U-18	HAUNCHED GIRDER CONSTRUCTION SEQUENCE
U-19	ERECTION BRACING
U-20	EXAMPLE ERECTION PLAN DETAILS

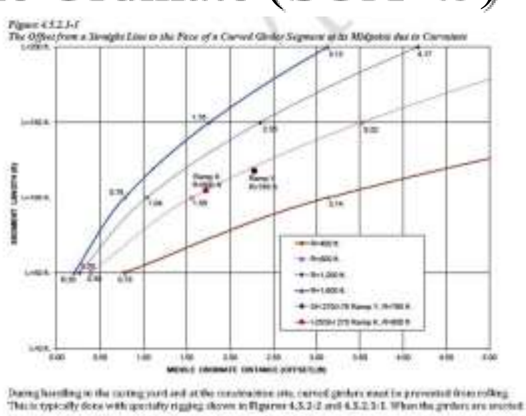
PCI Zone 6 U Beam Go By Sheets

- ***<u>WHY THIS TOOL?</u>***
- How the PCI Zone 6 Go-Bys work
- Quantity Estimates
- Special Details
- Conventional Details
- Considerations for Innovative Concepts approval
- Light Weight Aggregates

PCI *Innovative Solutions for tomorrow's transportation needs*

Curved Spliced U Girders

Middle Ordinate (SOA-49)



PCI *Innovative Solutions for tomorrow's transportation needs*

Precast Offers Solutions to Challenges

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TechnoQuest Trip to Colorado

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TechnoQuest Trip to Colorado

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Curved Spliced U Girders by CFX

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Curved Spliced U Girders by CFX

CFX Presentation Outline

- Introduction
- Project Overviews
- Design Details
- Design Criteria
- Technical Special Provisions
- Torsion – Demand and Capacity Checks

CFX Presentation Outline

- **Introduction**
- **Project Overviews**
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- **Design Criteria**
- **Technical Special Provisions**
- **Torsion – Demand and Capacity Checks**

Introduction

TechnoQuest 2012 - Colorado Bridges

Partial Summary of Recent Florida CFX U-Beam Designs

Project	Beam Depth	Max Span (L/D)	Bridge Width	Girder Spacing		Slab Depth		Web (Strands)
				Interior	Exterior	Girder	Overhang	
CFX – 253F 408 / 417	7'-0"	195'-6" (27.9)	45'-6"	24'-10"	10'-4"	10"	10"	10" (15)
CFX – 417-301 Boggy Creek (1)	7'-0"	215'-9" (30.8)	45'-3"	22'-8"	11'-3"	8-3/4"	10"	10" (15)
CFX – 417-301 Boggy Creek (2)	8'-0"	246'-11" (30.9)	43'-3"	23'-8"	9'-9"	9-1/2"	9-1/2"	10" (12 & 19)
CFX – 429-202 Wekiva	10'-0" (Pier) to 6'-0" (Mid)	195'-0" (19.5 to 32.5)	45'-6"	24'-10"	10'-4"	10"	10"	10" (15)

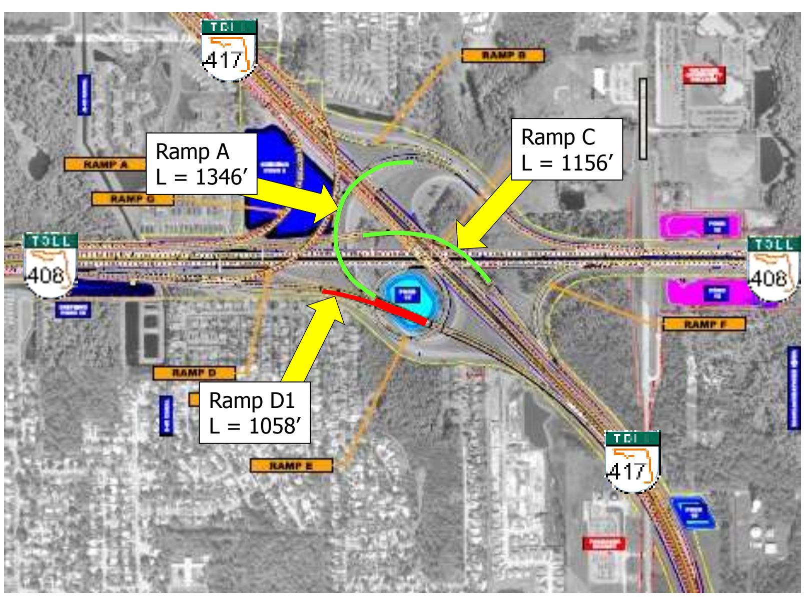
Design Dropped at 90% due to schedule constraints in reconfiguring layout and PT.

Project Overview

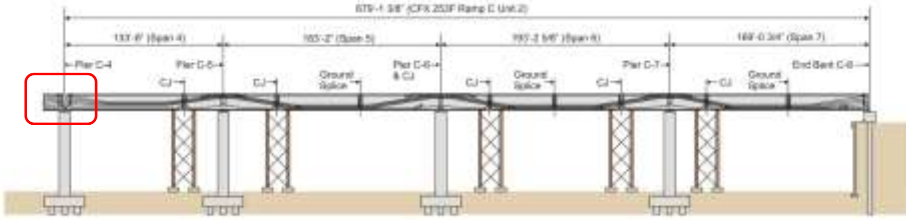
Design Intent

The 408/417 Design Basis developed by AECOM (Legacy URS) was adapted from segmental design philosophies. Thus, the stress limits used were generally formulated from segmental bridges. Also, the Special Provisions required an Erection Engineer to prepare an Erection Manual.

CFX 408/417 Interchange
Ramp C – Unit 2



Details: Tongue Section



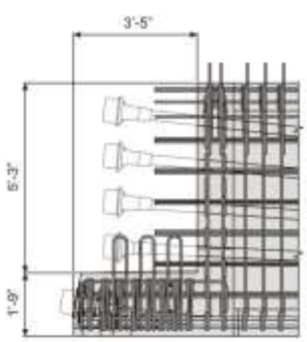
In the Yard

In the Field

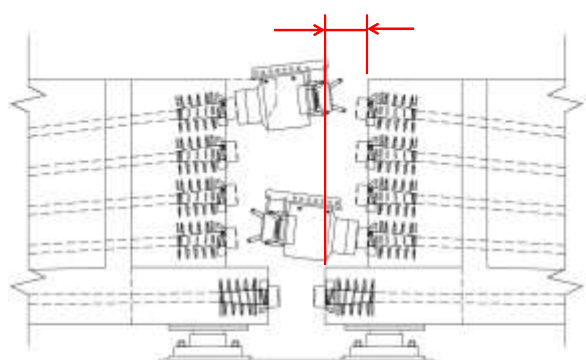
Reference – W. Nickas, PCI

Details: Tongue Section

Note: Post-Tensioning industry was consulted. There was concern about the length of tendons and jacking clearances.



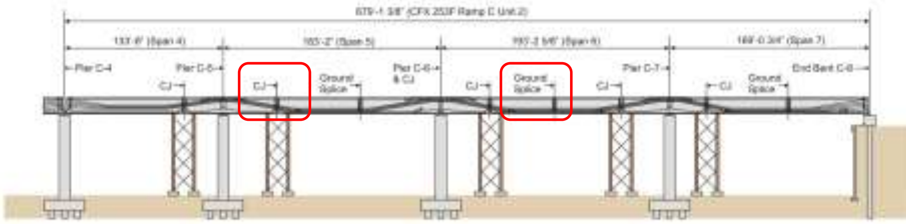
Elevation at End of Expansion U-Beam (Tongue Section)



Reference – W. Nickas, PCI

- Girders set on precast “tongue” section
- CIP Diaphragm cast against end of girder doubles as PT anchorage block
- Diaphragms designed to allow double end stressing with short stroke ram

Details: Closure Joints (CJ) & Ground Splices



In the Yard

In the Field

Geometric Details: Closure Joints (CJ) & Ground Splices

Superelevation Transitions

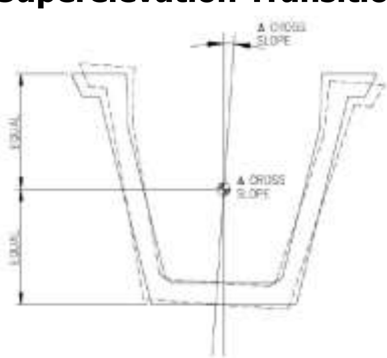
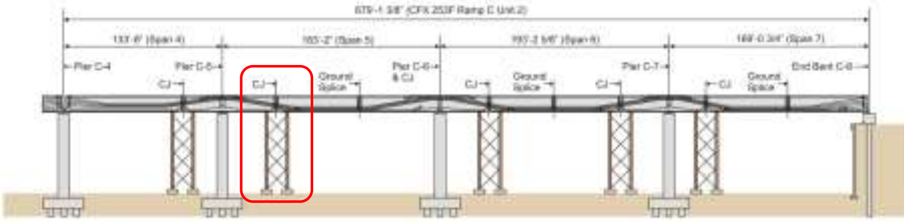


Fig. 4.9 U-girder point of rotation

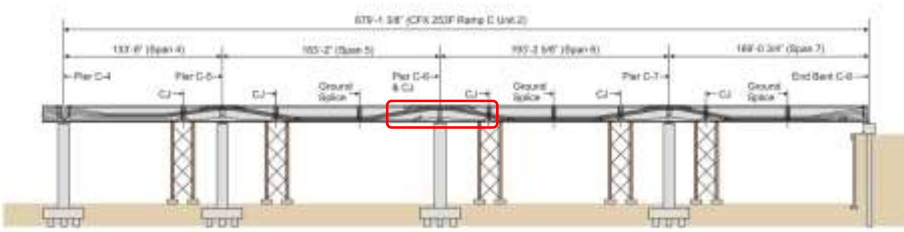
- **Limit Angle Offset at Splice Locations (Limit is Pending)**
- **Varying Haunch Build-Up Over Webs**

Prestressed Precast Concrete Institute, "Curved Precast Concrete Bridges State-of-the-Art Report (Draft), Received from William Nickas, Feb. 15, 2012.

Details: Temporary Falsework



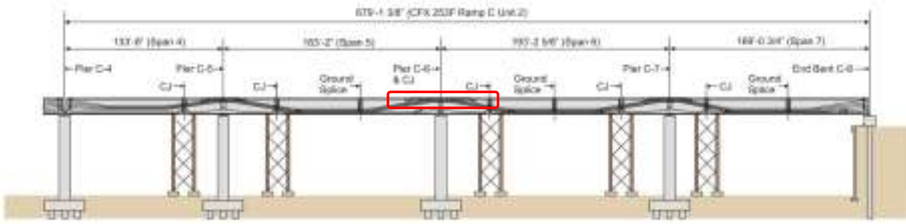
Details: Bottom Slab Thickening



Cast in the field

Cast in the yard

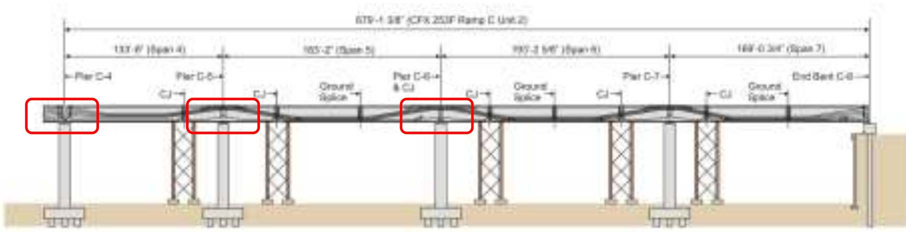
Details: Spot Tendons – Top PT



In the Yard

In the Field

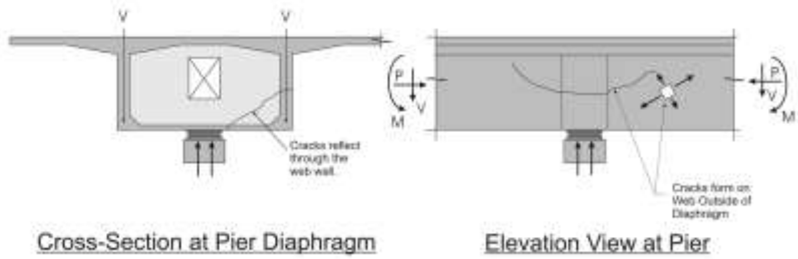
Details: Diaphragms

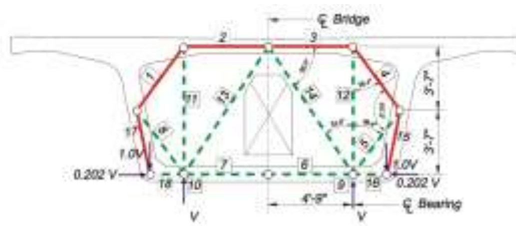


End Diaphragm

Intermediate Diaphragm

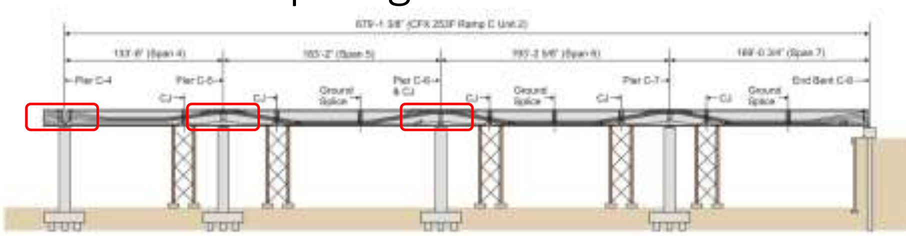
Details: Diaphragms



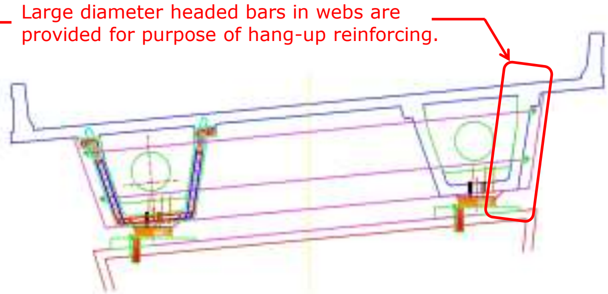


Figures from ACI Special Publication SP=273, 2010: Beaupre, Anderson and Bridges

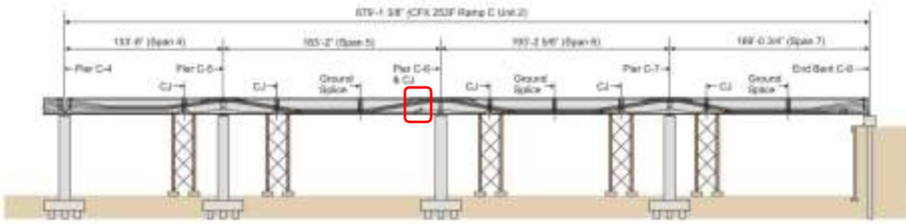
Details: Diaphragms

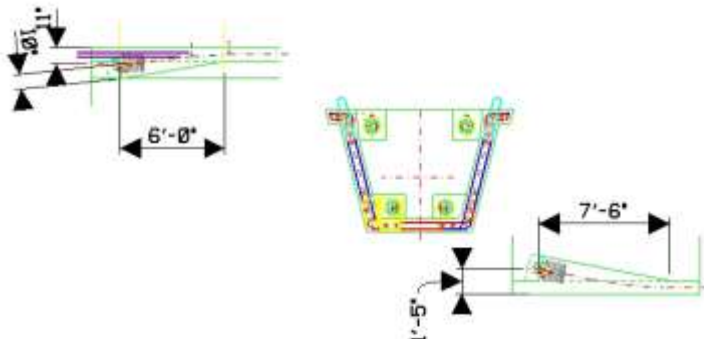


Large diameter headed bars in webs are provided for purpose of hang-up reinforcing.

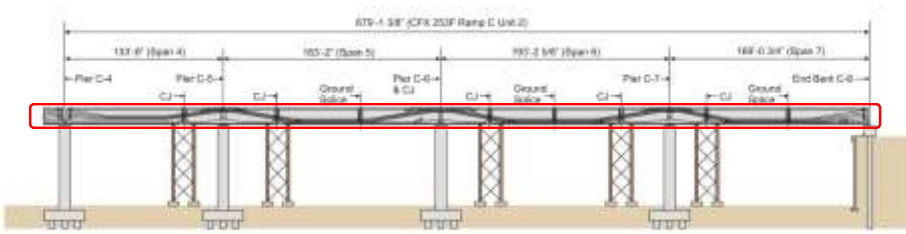


Details: Blisters





Details: Lid Slab

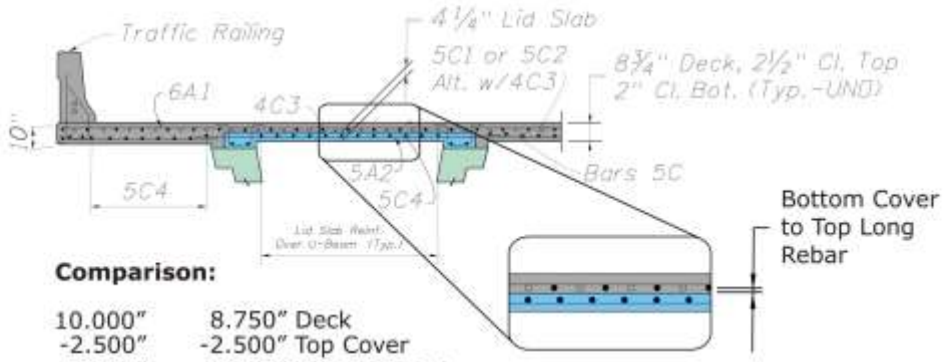


Reference – W. Nickas, PCI

Details: Lid Slab Top Longitudinal Cover

4 ¼" Lid Slab for 50 x Torsional Stiffness

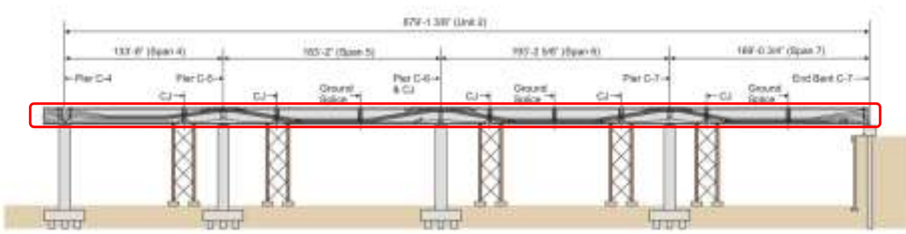
Final Slab ?



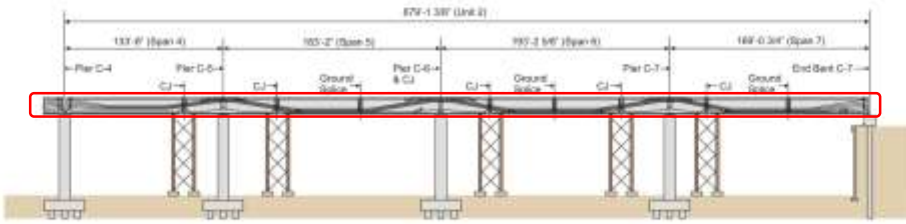
Comparison:

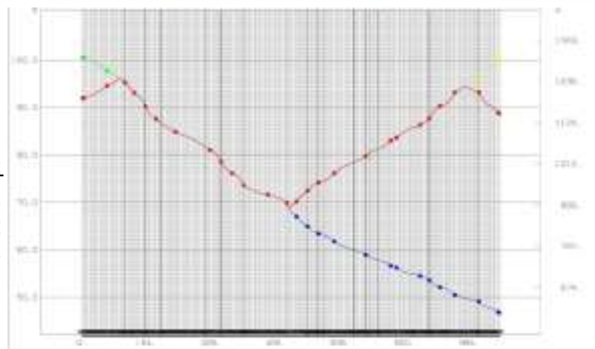
10.000"	8.750" Deck
-2.500"	-2.500" Top Cover
-0.750"	-0.750" Top Trans Rebar
-0.625"	-0.625" Top Long Rebar
-4.250"	-4.250" Lid Slab
1.875"	0.625" Bottom Cover to Top Long Rebar

Details: Tendon Profiles



Details: Tendon Profiles



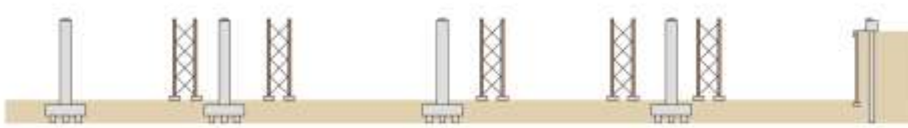


Per Cent - fpu

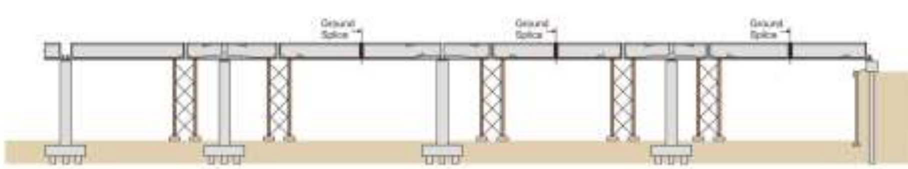
Length

Reference – T. Stelmack,
PCI TechnoQuest 2014

Construction Staging

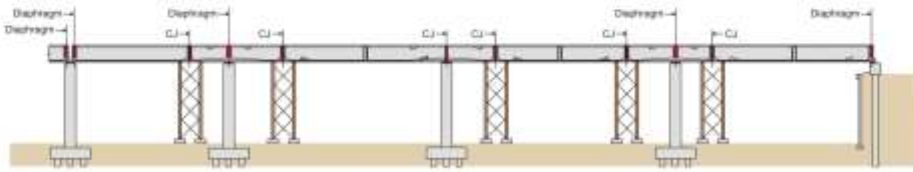


STAGE 1 - Erect Substructure and Falsework Towers

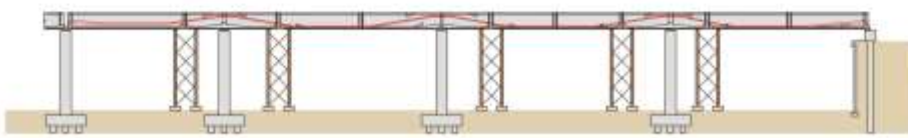


STAGE 2 – Cast Ground Splices, Post-Tension, and Erect Girders

Construction Staging



STAGE 3 - Cast Closures, Intermediate Diaphragms and End Diaphragms



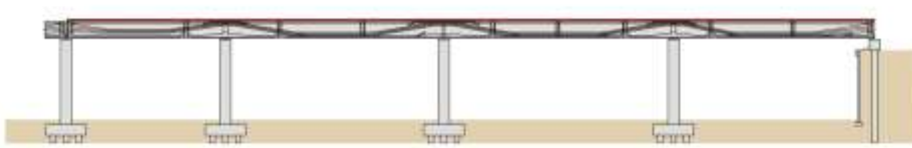
STAGE 4 - 1st Stage Continuity Post-Tensioning

Construction Staging

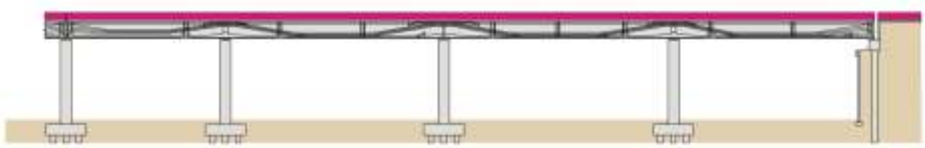
STAGE 5 - Cast Lid Slab

STAGE 6 - Remaining 2nd Stage Continuity Post-Tensioning and Cast Anchorage Covers

Construction Staging



STAGE 7 - Cast Deck Slab



STAGE 8 - Finishing Works

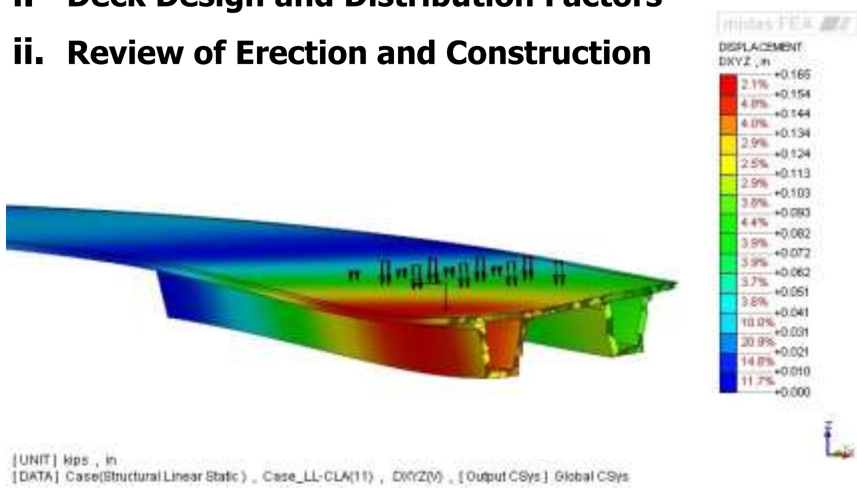
Design Flexibility: Skewed Supports

Superstructure Design & Modeling

Modeling - FEA

i. **Deck Design and Distribution Factors**

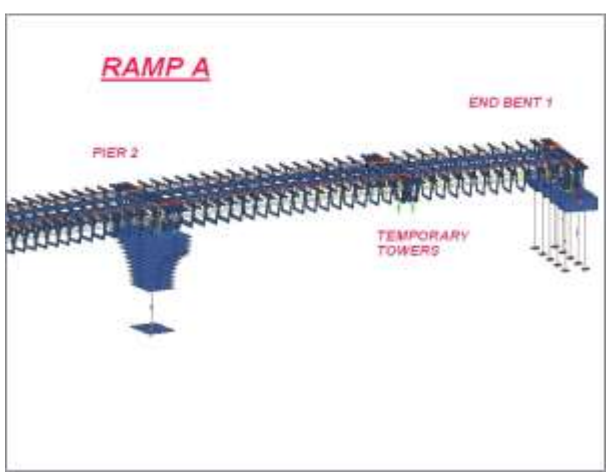
ii. **Review of Erection and Construction**



Superstructure Design & Modeling

Modeling

Time Dependent Analysis (Primary Model)



Transverse Reinforcing of Webs

- **Av = As Shear**
- **Af = As Transverse Flexure**
  - **Case 1: As tot = 1.0(Av) + 0.5(Af)**
  - **Case 2: As tot = 0.5(Av) + 1.0(Af)**
  - **Case 3: As tot = 0.7(Av + Af)**

- **Reinforce for Max. of Case 1, 2, or 3**

(Reference Podolny and Muller 1982)

Provisional Post-Tensioning

Not Required:

- **Provisional Strands**
- **Future PT Ducts and Strands**
- **Segment Drop Cases**

Longitudinal Tendons and Ducts

- **Minimum 4 Tendons per Web**
- **Horizontal and Vertical Spacing, the Max of:**
  - **4.00"**
  - **Outer Duct Dia. + 1.5 x Max. Aggregate Size**
  - **Outer Duct Dia. + 2"** ***<- Controls***
- **Assumed PT Duct Out-to-Out Diameters:**

  (FDOT SDG – Table 4.5.12-1)
  - **12-0.6" Strands – 3.58"**
  - **15-0.6" Strands – 3.94"**
  - **19-0.6" Strands – 4.57"**

Design Loadings

Permanent Loads

Self Weight	Density / Effect
Reinforced Concrete	150 lbs/ft^3
Plain Concrete w/o Reinforcement	145 lbs/ft^3
Post-Tensioned Concrete	155 lbs/ft^3
Structural Steel	490 lbs/ft^3
Sacrificial Deck Thickness	½ inch
Stay-In-Place (SIP) Metal Forms	20 lbs/ft^3

Superimposed Dead Loads	Weight
Future Wearing Surface	None
Traffic Railing Barriers (42" F Shape)	TBD
Traffic Median Barriers (Median 32"F Shape)	None
Utilities	TBD

Design Loadings

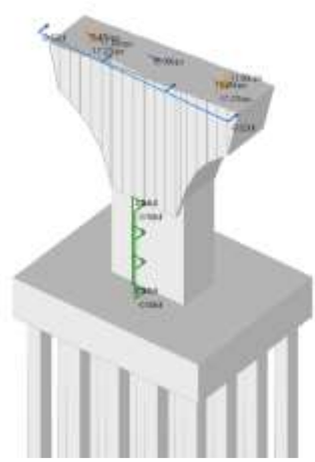
Wind Loads

Wind loads for bridges are computed in Accordance with the AASHTO LRFD and SDG Section 2.4 with

- 130MPH (Orange County) - AASHTO Load Combination Strength III and Service IV Limit State

and

- 78 MPH basic wind speed - AASHTO Load Combination Service I and Strength III (Construction)

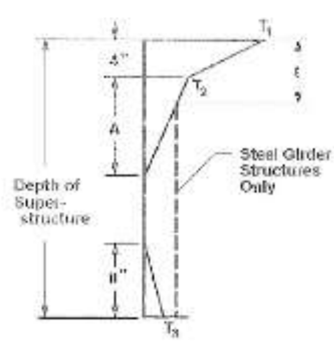


Design Loadings

Thermal Loads

- **Uniform Seasonal Temperature Rise and Fall (TU):**
  a. Temperature Rise = 35 ^{0}F
  b. Temperature Fall = 35 ^{0}F
  c. Range = 70 ^{0}F

Temperature Gradient (TG) – Needed?:
a. T1 = 41 ^{0}F
b. T2 = 11 ^{0}F
c. T3 = 0 ^{0}F



Design Loadings

Creep & Shrinkage (CRSH)

a. Strains are calculated in accordance with CEB/FIP Model Code for Concrete Structures, 1978
b. Relative Humidity: 75 %
c. Permanent effects of creep and shrinkage shall be added to all AASHTO LRFD loading combinations

Construction Loads (CE)

a. Minimum construction live load of 10 psf for all stages during erection and construction

b. Wind loads on permanent and temporary components during construction shall be per SDG Section 2.4.3

Design Criteria: Temporary Stresses

Temporary Stresses Before Losses (LRFD Table 5.9.4.1.2-1)	Design Stress Limit
Due to effective prestress, permanent loads, and transient loads due to shipping and handling. Estimate loads due to shipping and handling, applied in addition of the weight of the beam as 20% (up) and 50% (down) of the weight of the beam. (See also SDG 4.3.1 Section C.3.) **Curved precast concrete U-Beams are not required to meet the initial 1/2" upward camber requirement of SDG Section 4.7.**	**$0.190 \cdot \sqrt{f'ci}$ (ksi)** **$6.0 \cdot \sqrt{f'ci}$ (psi)**

"Suggest a minimum applied compression be established in addition to tension limit to avoid only mild steel being used for short U-Beam segments."

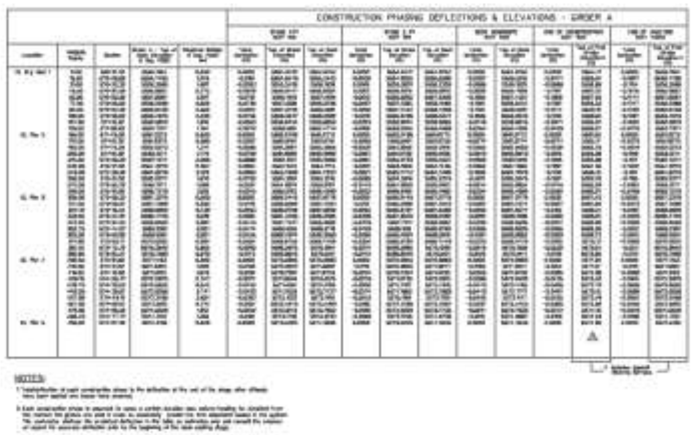
Geometry Control

Table – Construction Deflections and Elevations

Cambers/Deflections for Erection Stages

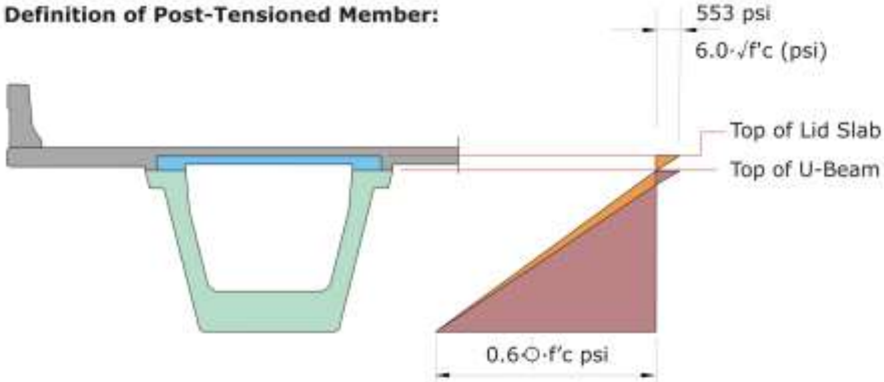
Haunch Thicknesses

Sample Table from Plans



Design Criteria: Longitudinal Tension

Definition of Post-Tensioned Member:



Should the Lid Slab be considered part of the post-tensioned member?

Yes, because the Lid Slab is intended to remain during deck rehabilitation.

Special Provisions
Construction Issues

Erection Manual

- **Step-by-step Sequence, Girder Age, Closure Pour Age**
- **Temporary Works / Falsework**
  - **Active jack system shown in Contract Documents**
  - **Construction load factors were not explicitly defined**
  - **Falsework Location and Loads/Max Deflections**
  - **Cambers / Haunch Thicknesses (Reconfirmed)**
  - **Contractor Responsible for Stability of Temporary Works**
- **Equipment, Post-Tensioning and Grouting**
- **Field Survey and Geometry Control**
- **Time Dependent Analysis / Stress and Force Summary**

Special Provisions
Construction Issues

Construction Engineering Report

"The Construction Engineer Report shall include the Table of Contents, Basis of Design, Erection Manual, and Geometry Control Manual."

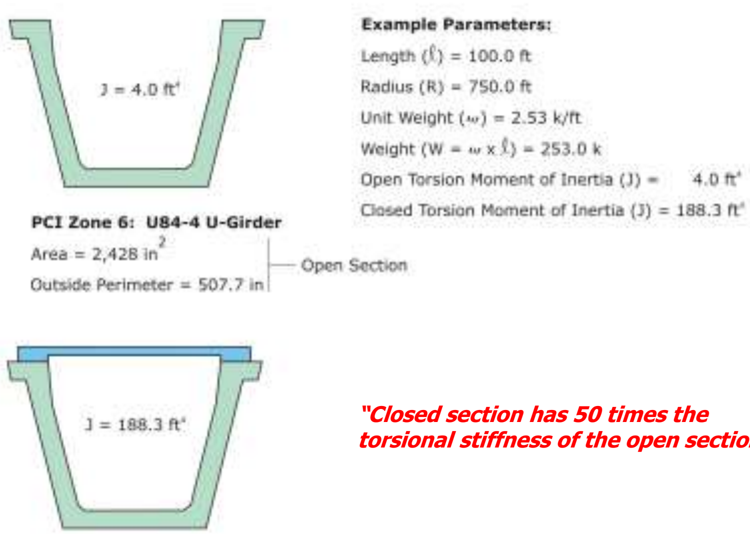
Special Provisions Construction Issues

Geotechnical Information

(Active jack falsework system shown on plans)

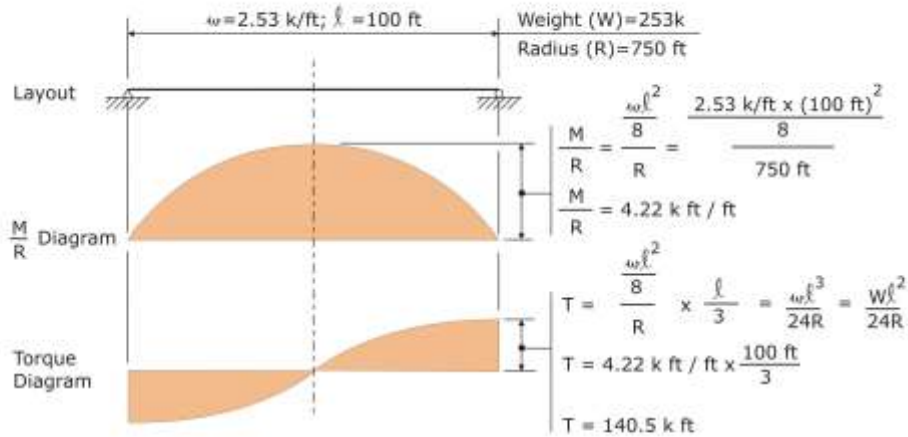
"The Contractor is responsible to obtain recommendations for: a) soil bearing or pile capacities; and, b) soil pressures induced on temporary shoring. These recommendations shall be signed and sealed by a Professional Engineer registered in the State of Florida and submitted to the Engineer for review."

Torsion Evaluation: Prototype Section



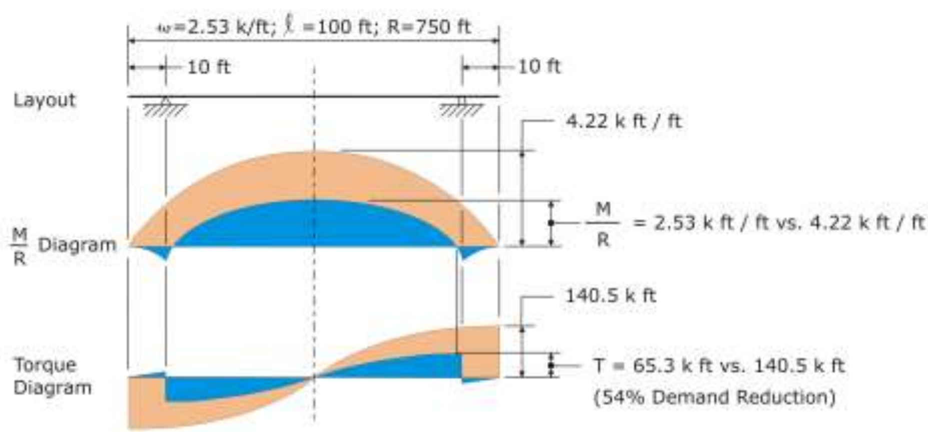
"Closed section has 50 times the torsional stiffness of the open section."

Torsional Demand



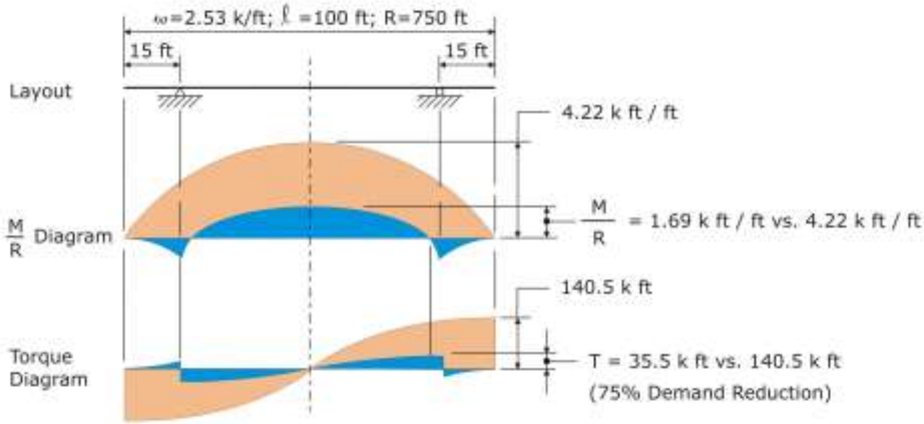
Reference – PCI Bridge Design Manual 3rd Edition, August, 2014: – Page 12-24; Figure 12.5.2.1-2

Torsional Demand

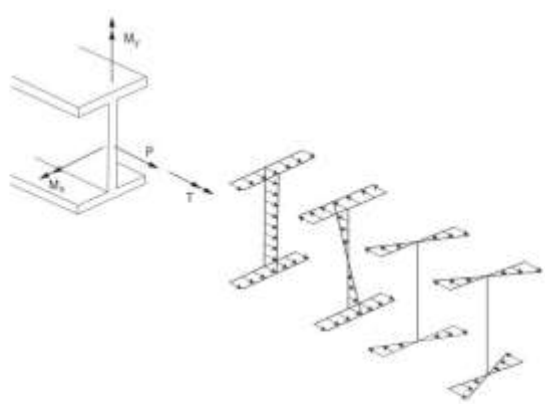


"Moving the supports inboard 10% cuts the torsional demand by more than half."

Torsional Demand



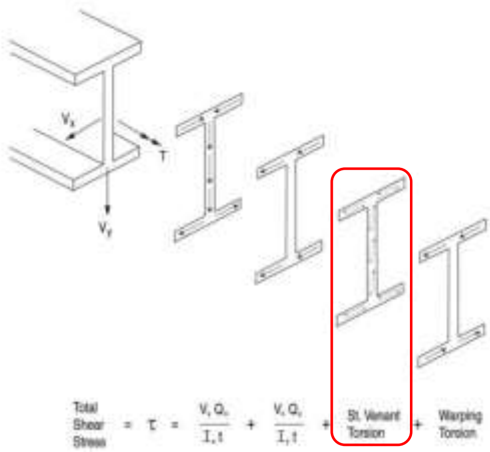
Normal Stresses



$$\text{Total Normal Stress} = \sigma = \frac{P}{A} + \frac{M_x\, y}{I_x} + \frac{M_y\, x}{I_y} + \text{Warping Normal Stress}$$

Source: FHWA Steel Bridge Design Handbook - Volume 8, November 2012

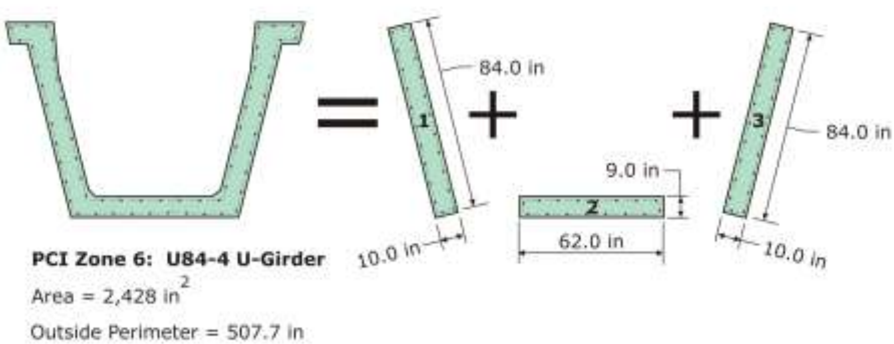
Shear Stresses



A. J. C. B. Saint-Venant, 1855, Memoire sur la Torsion des Prismes, Mem. Divers Savants, 14, pp. 233–560

Source: FHWA Steel Bridge Design Handbook - Volume 8, November 2012

Torsional Capacity – St. Venant



Torsional Capacity – St. Venant

Elastic theory (Timoshenko & Goodier 1969; Popov 1990)

$Tcr = \alpha(x^2 y)6\sqrt{f'c}$ (Without Prestress)

Piece	α	x	y	$f'c$	Tcr
1	0.300	10.0 in	84.0 in	8,500 psi	116.2 k ft
2	0.300	9.0 in	62.0 in	8,500 psi	69.5 k ft
3	0.300	10.0 in	84.0 in	8,500 psi	116.2 k ft
				Total	301.8 k ft

$\phi\ Tcr\ /\ 4 =$ 0.9 x 301.8 k ft / 4 = 67.9 k ft (Capacity)

Torsional Capacity – St. Venant

Space Truss Analogy (ACI 318-99 1999)
AASHTO LRFD Equation 5.8.2.1-4 (psi)

$Tcr = (A_c^2/P_c)\ 4\sqrt{f'c}$ (Without Prestress)

Piece	A_c	P_c	$f'c$	Tcr
1	840.0 in^2	188.0 in	8,500 psi	115.3 k ft
2	558.0 in^2	142.0 in	8,500 psi	67.4 k ft
3	840.0 in^2	188.0 in	8,500 psi	115.3 k ft
			Total	298.1 k ft

$\phi\ Tcr\ /\ 4 =$ 0.9 x 298.1 k ft / 4 = 67.1 k ft (Capacity)

Torsional Capacity – St. Venant

Space Truss Analogy (ACI 318-99 1999)
AASHTO LRFD Equation 5.8.2.1-4 (psi)

$Tcr = (A_c^2/P_c)\ 4\sqrt{f'c}$ (Without Prestress)

Piece	A_c	P_c	$f'c$	Tcr
1 + 2 + 3 	2,428.0 in²	507.7 in	8,500 psi	356.9 k ft
				——
				——
			Total	356.9 k ft

$\phi\ Tcr\ /\ 4 =$ 0.9 x 356.9 k ft / 4 = 80.3 k ft (Capacity)

Torsional Capacity – St. Venant

Space Truss Analogy (ACI 318-99 1999)
AASHTO LRFD Equation 5.8.2.1-4 (psi)

(Without Prestress)

$$Tcr = (A_c^2/P_c)\ 4\sqrt{f'c}$$

(With Prestress)

$$Tcr = (A_c^2/P_c)\ 4\sqrt{f'c}\ \sqrt{1 + \frac{fpc}{4\sqrt{f'c}}}$$

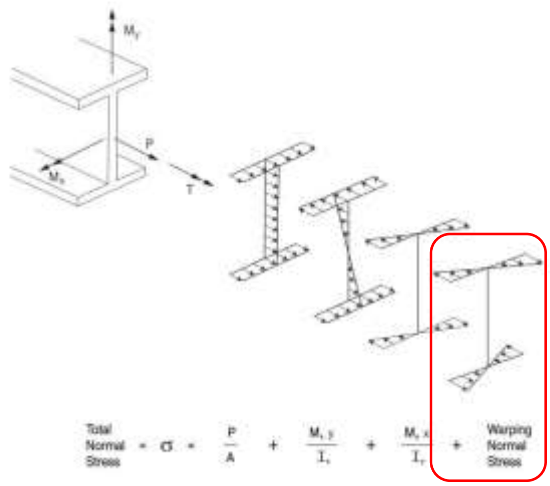
(With Prestress Equal Two 0.6"dia. 7-Strand Tendons)

$$Tcr = (A_c^2/P_c)\ 4\sqrt{f'c}\ \sqrt{1 + \frac{2 \times 246k \times 1000lb\ /\ k\ \ /\ 2{,}429in^2}{4\sqrt{f'c}}}$$

$$\phi\ Tcr\ /\ 4 = 0.9 \times 299.8\ \text{k ft} \times 1.276 = \ 86.1\ \text{k ft}\ (6{,}000\text{psi})$$

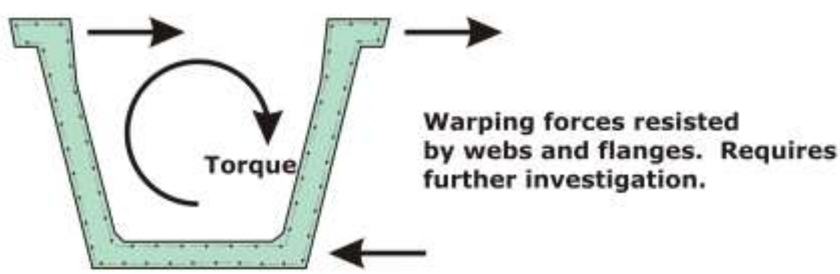
$$\phi\ Tcr\ /\ 4 = 0.9 \times 356.9\ \text{k ft} \times 1.245 = 100.5\ \text{k ft}\ (8{,}500\text{psi})$$

Normal Stresses



Source: FHWA Steel Bridge Design Handbook - Volume 8, November 2012

Torsional Capacity

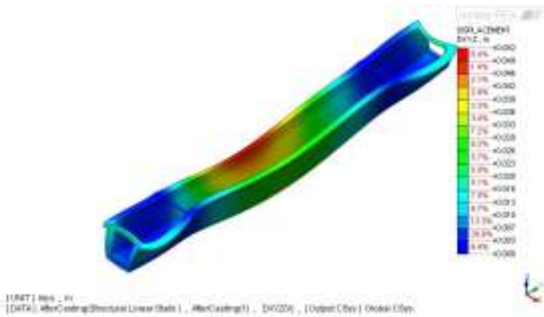


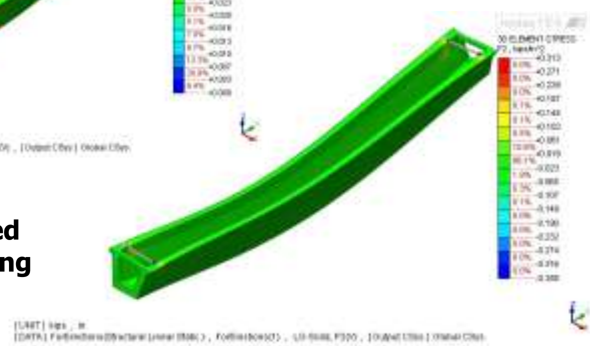
PCI Zone 6: U84-4 U-Girder

Area = 2,428 in^2

Outside Perimeter = 507.7 in

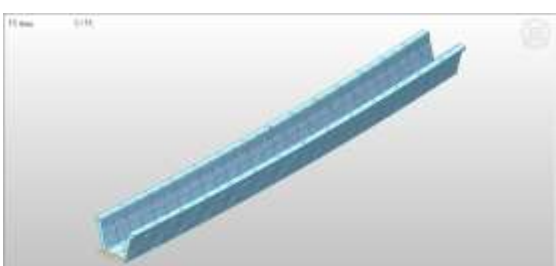
Torsion & Shear Study
Finite Element Model

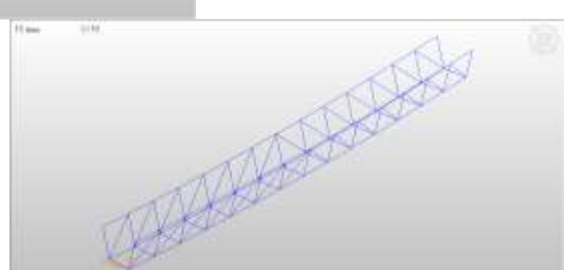




Additional work planned for evaluation of warping stresses.

Torsion & Shear Study
Space Frame Model





Additional work planned for evaluation of warping stresses.

Curved Spliced U Girders

PAST FACTS

- The advancement of curved spliced U-Beam bridge technology has progressed principally in Colorado over 20 years and has evolved through a collaboration of designer, contractor, and owner. Much of the current technology is in its 2nd or 3rd generation. Many of the predecessor projects were delivered under the design-build project delivery system.

Curved Spliced U Girders

PAST FACTS

- This has allowed the technology to receive direct contractor input to obtain constructable and economically feasible solutions.
- Curved, spliced U-Beam bridge technology is stirring much interest. Agencies and builders have shown interest in replication in several areas of the country. However, there are certain areas of practice that have not been quantified. This makes it difficult for the owners and the design community to fully embrace the technology.

Curved Spliced U Girders by PCI Zone 6

Typical section with constant bottom slab thickness

Typical section with variable bottom slab thickness

Option 2 with precast panels

Option 2 CIP Lid Slab

Option 2 Light Weight Concrete

Option 2 19K6 with 10 inch webs

Curved Spliced U Girders by PCI Zone 6

GIRDER GEOMETRY

GIRDER	D	DUCT SIZE	tw	W	T	B	B'	WEIGHT
[illegible]	6'-0"	3"ø	9"	10'-1"	6'-6"	1'-6"	5'-10"	[illegible] plf
[illegible]	7'-0"	3"ø	9"	10'-1"	7'-3"	1'-6"	5'-10"	2,349 plf
[illegible]	8'-0"	3"ø	9"	11'-1"	7'-6"	1'-6"	6'-10"	[illegible] plf
[illegible]	6'-0"	4"ø	10"	10'-3"	6'-6"	1'-6"	6'-0"	[illegible] plf
[illegible]	7'-0"	4"ø	10"	10'-8"	7'-3"	1'-6"	6'-0"	2,520 plf
[illegible] HAUNCH	–	4"ø	–	–	–	–	–	[illegible] kips
[illegible]	8'-0"	4"ø	10"	11'-3"	7'-9"	1'-6"	6'-0"	[illegible] plf

Curved Spliced U Girders by PCI Zone 6

Maximum Span Lengths

U72					
BOTTOM SLAB	PRECAST PANELS	CIP LID SLAB	CONCRETE	TENDONS (PER WEB)	L_{MAX}
CONSTANT	NO	NO	NORMAL	3 x 12–0.6"φ	165'–0"
VARIABLE	YES	NO	NORMAL	4 x 12–0.6"φ	185'–0"
VARIABLE	NO	NO	NORMAL	4 x 12–0.6"φ	200'–0"
VARIABLE	NO	YES	NORMAL	4 x 12–0.6"φ	205'–0"
VARIABLE	NO	YES	LIGHTWEIGHT	4 x 12–0.6"φ	220'–0"
VARIABLE	NO	NO	NORMAL	3 x 19–0.6"φ	220'–0"

U84					
BOTTOM SLAB	PRECAST PANELS	CIP LID SLAB	CONCRETE	TENDONS (PER WEB)	L_{MAX}
CONSTANT	NO	NO	NORMAL	3 x 12–0.6"φ	195'–0"
VARIABLE	YES	NO	NORMAL	4 x 12–0.6"φ	205'–0"
VARIABLE	NO	NO	NORMAL	4 x 12–0.6"φ	220'–0"
VARIABLE	NO	YES	NORMAL	4 x 12–0.6"φ	225'–0"
VARIABLE	NO	YES	LIGHTWEIGHT	4 x 12–0.6"φ	235'–0"
VARIABLE	NO	NO	NORMAL	4 x 19–0.6"φ	265'–0"

U96					
BOTTOM SLAB	PRECAST PANELS	CIP LID SLAB	CONCRETE	TENDONS (PER WEB)	L_{MAX}
CONSTANT	NO	NO	NORMAL	3 x 12–0.6"φ	205'–0"
VARIABLE	YES	NO	NORMAL	4 x 12–0.6"φ	215'–0"
VARIABLE	NO	NO	NORMAL	4 x 12–0.6"φ	230'–0"
VARIABLE	NO	YES	NORMAL	4 x 12–0.6"φ	240'–0"
VARIABLE	NO	YES	LIGHTWEIGHT	4 x 12–0.6"φ	250'–0"
VARIABLE	NO	NO	NORMAL	4 x 19–0.6"φ	280'–0"

Curved Spliced U Girders

PAST FACTS Continued:

- In nearly all documented cases, this solution has resulted in significant savings in initial cost compared to alternative solutions. Considering the life-cycle costs of longevity and maintenance, the initial cost, and aesthetic advantages, the benefits of this solution promise to be dramatic.

Curved Spliced U Girders

The Future

1. Curved U-Beam Concept
    a. Precast Section
        i. Formwork and Cross Section
        ii. Introduction of Post-Tensioning
2. Projects in Colorado and Florida
3. Design Criteria
    a. Designer Role and Stated Assumptions
    b. Limit States
        i. Longitudinal
            1. Strength I and II
            2. Strength IV (how often and where did Strength IV control)
            3. Service I and II
        ii. Principle Web Stress
    c. Technical Specifications–Discussion of Tech Specs provided in Appendix 3

Curved Spliced U Girders

- **Proposed Outline (Continued)**
    d. Specialty Engineer Role and Submittals
        i. Specialty Engineer and EOR
        ii. Criteria Curing Construction
        iii. Load Cases in Plant Handling
            1. One-half the Cracking Torque
            2. Computations Required
        iv. Camber Diagrams and Field Measurements
        v. Site Monitoring and Stability
4. Span Layout
    a. Use of Straight and Curved Sections
        i. Simple Span
        ii. Continuous Solutions
    b. Typical Section

Curved Spliced U Girders

- **Proposed Outline (Continued)**

5. Longitudinal Modeling
    a. Materials
    b. Age at Construction
    c. Splice Locations and Boundary Conditions
    d. Temporary Works– Sensitivity to Falsework Support Settlement
    e. Compression Controlled
    f. Pier Fixity—Discussion of Integral Superstructure Versus Isolation at Intermediate Piers
    g. Parametric Study for Post-Tensioning Requirements—<u>Plot additional data points on existing PCI Zone 6 Charts for Example 3-Span Continuous Structure with the following layouts and boundary conditions</u>

Curved Spliced U Girders

Proposed Outline (continued)

h. Three Dimensional Modeling—Flexure, Shear and Torsion
i. Principal Web Stress
j. Geometry Control
    i. Camber Requirements
    ii. Rotating sections at falsework towers to match superelevation
    iii. Build-Up Calculation

6. Transverse Modeling
    a. Distribution Factor Analysis
    b. Transverse Slab Analysis
7. General Design Considerations
    a. Shipping and Hauling
        i. <u>Cracking Torque</u>
        ii. Overturning
        iii. Tension and Cracking

PCI
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Curved Spliced U Girders

Proposed Outline (continued)

7.b. Temporary Bracing
- i. Temporary Tower Size and Configuration
- ii. Lateral Loads and Sway Bracing in Towers

c. Sectional Design for Ultimate Limit State
- i. Longitudinal Reinforcing Check
- ii. Transverse Web Reinforcing
  1. Combined shear and Torsion in LRFD EQ 5.8.3.6.3-1
  2. Combined shear and web bending–Investigation of Poldony's recommendation for segmental bridges.
- iii. Reinforcing Parameters—Explain/develop general rules of thumb for girders in terms of lbs/lf or lbs/cy

Curved Spliced U Girders

Proposed Outline (continued)

8. Design Details
   - a. Bridge Typical Section and Post-Tensioning
   - b. Lid Slab
   - c. Diaphragms
   - d. Bearings
9. References

Appendix 1–Abbreviated Design Criteria

Appendix 2–Design Details
- a. CIP Lid Slab Details
- b. CIP Deck Details–Over lid slab and interface shear connectors
- c. Interior haunch connection and form saver details
- d. Spot tendon verses full length

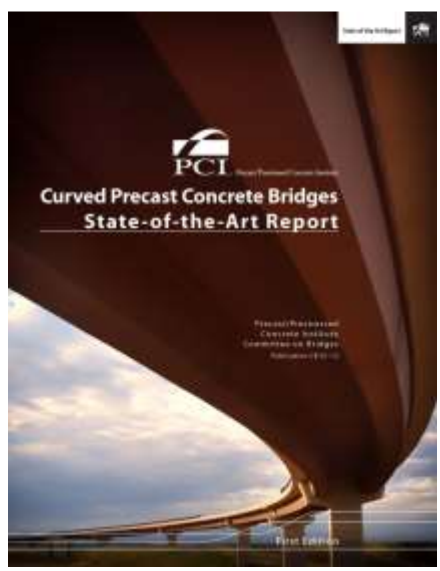
Appendix 3–Sample Specifications

Appendix 4–Example Calculations
- a. Example Table of Contents
- b. Calculation Excerpts from Key Sections

- A webinar presentation by Colorado Engineers, December 18, 2014 titled "Colorado Flyover Ramp Showcases Precast Pier Caps and Curved Spliced Precast U-Girders" offers an excellent primer on this product and bridge solution used on nine bridges in Colorado. It can be found at the FIU Accelerated Bridge Construction Center, Florida International University, Miami, FL. The link to the 1-hour video is below.
- http://abc-utc.fiu.edu/index.php/technology/monthly_webinar_archive/view/colorado-flyover-ramp-showcases-precast-pier-caps-and-curved-spliced-precas
- Proven competitive and constructible, a new solution is now available in the owner agency's repertoire. It provides a rapid, economical solution that will withstand the test of time.

Innovative Solutions for tomorrow's transportation needs

Curved Precast Concrete Bridges
State-of-the-Art Report
(CB-01-12)



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Credits

- Central Florida Expressway Authority
- URS/AECOM peer review consultant
- Dewberry - Prime
  - PARSONS – Ramps H & I Design as a sub
- A[2] Group – CEI
  - FIGG as a sub
- SEMA Construction
  - Summit Engineering as contractors engineer
  - Durastress as Precaster
  - Freyssinet as PT supplier and installer

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