Prestressed Concrete Bridge Design Seminar

Session 1 – November 1, 2022

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Session 1 - Agenda

Session One - Tuesday, November 1, 2022			
Topic	**Begin**	**Duration**	**Presenter**
Welcome & Introduction	11:00 AM	0:10	RL
Basic Concepts of Prestressed Concrete	11:10 AM	0:20	RWC
Fabrication of PS Girders	11:30 AM	1:00	RWC
Virtual Plant Tour	12:30 PM	0:30	LB
Economical Detailing of PS Girders	1:00 PM	0:20	RWC
Q&A	1:20 PM	0:10	RL or other
PCI West Wrap-up	1:30 PM		

Reid W. Castrodale, PhD, PE

Castrodale Engineering Consultants, PC – Concord, NC

- **Structural engineering consultant - Prestressed concrete, LWC, and ABC**
- **39 years bridge experience in design, research, promotion, & specifications**
  - **Formerly Portland Cement Assn. (PCA), Ralph Whitehead Assoc. (now STV), and Stalite**
  - **Georgia/Carolinas PCI Bridge Consultant (~ 25 yrs)**
  - **Managing Technical Editor of *ASPIRE*™ magazine – *now Emeritus***
  - **Director of Engineering – ESCSI & Stalite – Lightweight aggregate industry**
  - **Consultant on 5 NCHRP research project teams: 0.7” strand; deck girders; stainless steel strand; …**
- **Chair, PCI Committee on Bridges (1992-1998)**
- **Co-Chair, *PCI Bridge Design Manual* Steering Committee (1993-2011)**
- **NCHRP Report 517 “Extending Span Ranges of PC PS Concrete Girders”**

Education

- **Georgia Institute of Technology, BCE**
- **University of Texas at Austin, MS & PhD in Structural Engineering**

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Basic Concepts of Prestressed Concrete Design

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Why use Prestressed Concrete?

“Transforms” concrete from a material that cracks into an elastic uncracked material

- Prevents concrete cracking at service limit state
- Gross cross-section maintained for improved stiffness
- Provides active force to close flexural cracks
- Prestress force balances loads

An ideal combination for bridges

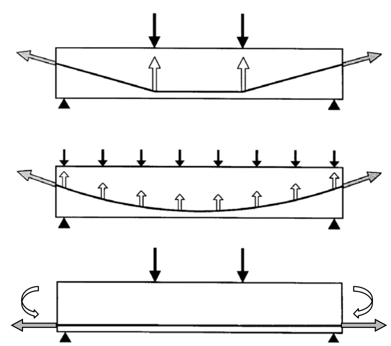
- Allows longer and/or shallower spans
- Improves durability

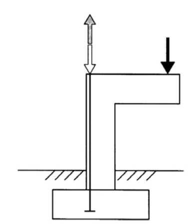
Adaptable to many design situations

Prestressed Concrete

High strength steel is pre-tensioned (i.e., prestressed) to pre-compress concrete to counteract tensile stresses and cracking at service limit state

Prestressing “balances” the applied loads



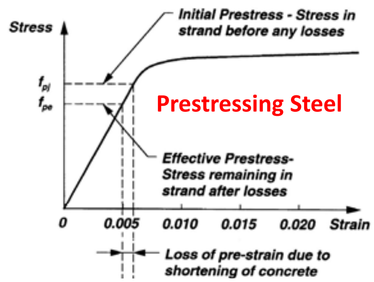


Prestressed Concrete

Prestressed (PS) concrete combines

- High performance concrete
- High strength steel

High strength prestressing steel is <u>required</u> to overcome strains from elastic shortening, creep, & shrinkage and still have significant stress



Prestressed Concrete

Prestressed (PS) concrete combines

- High performance concrete
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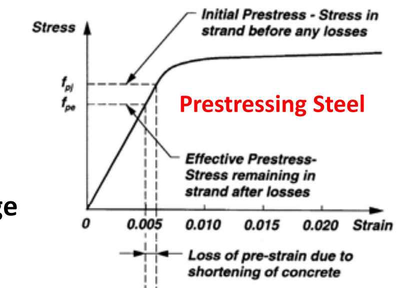
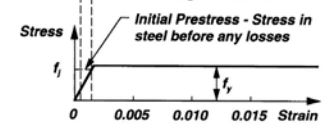
High strength prestressing steel is <u>required</u> to overcome strains from elastic shortening, creep, & shrinkage and still have significant stress

Mild reinforcement is not effective for prestressing – not enough strain capacity to overcome other strains



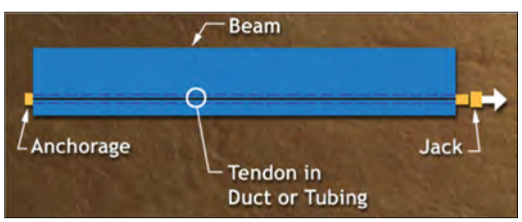


Mild Reinforcement

Post-tensioning

One method for applying prestress to concrete

- Ducts cast into concrete (CIP or precast)
- Strands are tensioned against hardened concrete member
- Force is transferred from strand to concrete by anchorage hardware
- After stressing, duct is typically grouted for bond and corrosion protection

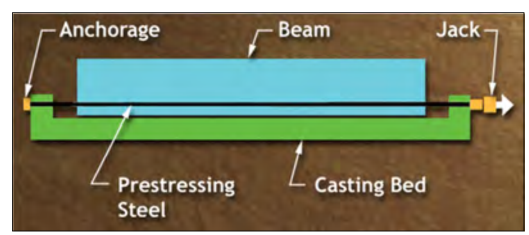


Many figures in this session are from the <u>PCI Bridge Design Manual</u>

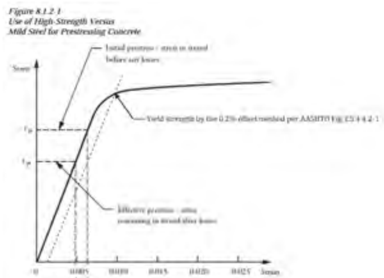
Pretensioning

Second method for applying prestress to concrete

- Strands are tensioned between abutments, then concrete is placed
- When concrete reaches the required initial strength, the prestress force is transferred from strands to concrete
- Force is transferred to concrete by bond only - there is no permanent anchorage hardware



Prestressing Strand

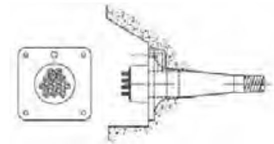


- 7–wire strands are standard
- 0.6 in. diam. strand is typical
- *0.7 in. diam. strand is being studied*
- *Also stainless steel, carbon fiber, and epoxy coated for corrosion resistance*

- Grade 270 strands are standard
- 270 ksi ultimate strength (GUTS)
- No defined yield point – use 0.2% offset = 243 ksi
- *Grade 300 strand is now available*

Post-Tensioning Anchors

Permanent hardware to anchor tendons



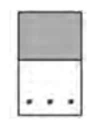
Pretensioned Concrete Beams

No tendon anchor hardware – anchorage by bond only

Compare Reinforced and PS Concrete

At Service Limit State Conditions

- Reinforced Concrete: Cracked section, Reduced stiffness



- Prestressed Concrete: Uncracked section, Gross section stiffness

At Strength Limit State Conditions

- Reinforced Concrete: Reinforcement yields
- Prestressed Concrete: Strands are past "yield", nearing strength
- Concrete stress block is the same for either

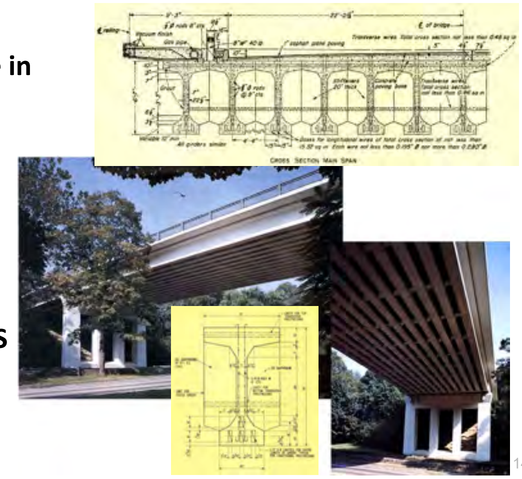
Benefits of Prestressed Concrete

- Structural Efficiency
- Cost Effectiveness
- Durability – crack control and high quality precast concrete
- Low Maintenance
- Quality – PCI certified
- Standardization
- Aesthetics
- Accelerated Bridge Construction (ABC)
- Fire Performance
- Proven Track Record

History of Prestressed Concrete

Introduced in the US in 1949

- Walnut Lane Memorial Bridge in Philadelphia, PA
- An innovative bridge
  - Girders precast on-site
  - Post-tensioned using wires
  - 160 ft main span
- Sparked the emergence of prestressed concrete in the US
- Bridge was replaced in 1990
  - See articles in *PCI Journal*, especially May-June 1992



History of Prestressed Concrete in CA

Arroyo Seco Bridge, near South Pasadena, CA

- A state-owned pedestrian bridge designed in 1950 as a reinforced concrete structure
- Post-tensioned beams were precast, then transported & erected; completed in May 1951
- Assoc. Prof. T.Y. Lin was involved

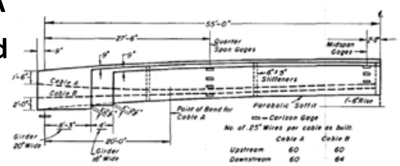


Fig. 9. Completed girders at casting site in Arroyo Seco Park.

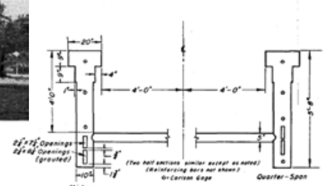


Fig. 4. Cross section of Arroyo Seco Pedestrian Overpass.

Two figures from article in *PCI Journal*, March-April 1979
Left photo taken in 1968; from Library of Congress

Growth of the Industry

Other developments in 1950s that enabled the rapid growth of pretensioned girders in the US

- Seven-wire strand
- Plant pretensioning in long-line beds
- Chemical admixtures
- High-early strength concrete
- Steam curing

By 1958, there were more than 200 prestressing plants in the US

Growth of the Industry

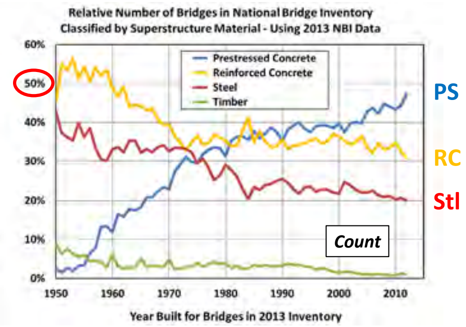
- Design standards were still evolving and developing
- Industry saw need to focus on quality
- PCI's Plant Certification program was developed
  - In place since 1967
  - Assures specifiers that plants have processes and capability to consistently produce quality products
  - Certification programs are also available for plant personnel
  - 41 state DOTs currently require PCI certification for prestressed concrete bridge products
    - Nevada DOT requires PCI Certification for prestressed concrete plants and personnel; Caltrans does not

Quality Assurance

- Quality is controlled during production at precasting plant
  - Rigorous inspections
  - Product is inspected at each stage of fabrication to provide quality control
  - PS concrete members are essentially load-tested at transfer of PS, giving an indication of quality

Growth in Use of PS Concrete Bridges

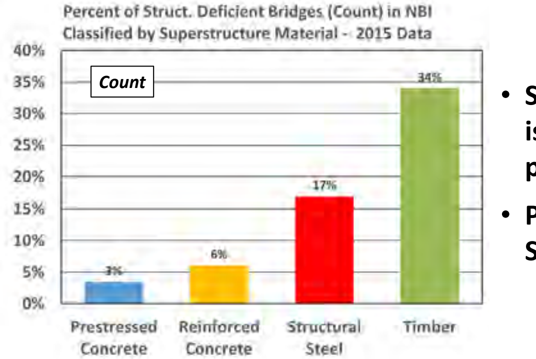
- Current preference for prestressed concrete in the US is revealed in the NBI data (2013) for total inventory (all states)
  - Nearly half of the number of new bridges (count) built each year are PS concrete – from none in 1950
  - PS concrete is only super-structure material with growth since 1950
- Using the FHWA InfoBridge Portal, 46% of bridges constructed in most recent 5 yr period were PS Concrete
  - Consistent with earlier data



Data source: FHWA Report "Bridges by Year Built, Year Reconstructed and Material Type" for 2013

PS Concrete Bridge Performance

- Structural deficiency of bridges of equal ages - based on superstructure material using NBI data



- Superstructure material is a significant factor in performance
- PS Concrete has fewest SD bridges

Data source: FHWA NBI Webpage "Deficient Bridges by Superstructure Material 2015"

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Basic Concepts of Prestressed Concrete Design

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Economical Fabrication of Prestressed Girders

Overview

Economical fabrication depends on economical design and detailing
- Process and details of fabrication
- Design considerations (later presentations)

Much info from *PCI Bridge Design Manual*
- Chapter 2 – Material Properties
- Chapter 3 – Fabrication & Construction
- Chapter 4 – Strategies for Economy
- Chapter 6 – Preliminary Design

Many fabrication details are possible – a few examples are shown

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Prestress Plants

- PS beds
- Batch plant
- Fabrication
- Storage and shipping
- Office

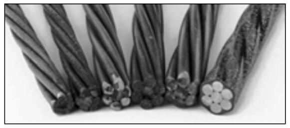
Materials

Prestressing strand

Mild reinforcement

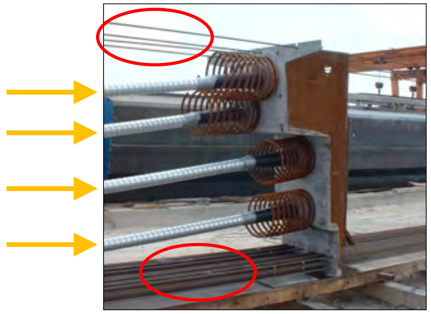
Concrete

Prestressing Strand



Prestressing strand
ASTM A416 Grade 270

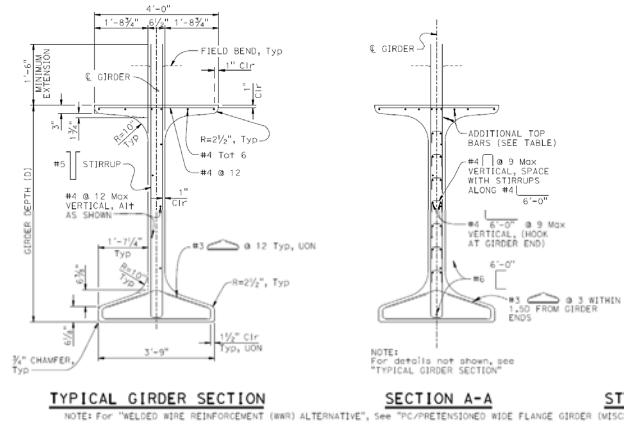
Strand shipped in coils



Pretensioned strands and post-tensioning ducts, anchorages, and spirals

Pretensioning and post-tensioning can be combined as shown here

Mild Reinforcement



Concrete

Conventional methods for proportioning and mixing concrete

- High strength mixes – typically up to 8.5 ksi at 28 days; can go to 10 ksi
- Rapid early strength gain is preferred so girders can be removed from the beds quickly to allow reuse of bed
- High flow mixes to move through congested reinforcement

Aggregate conveyer

Batch plant discharge

Fabrication

Forms

Casting beds

Strands – straight & harped

Tensioning & ducts

Embedments

Casting operations

Forms

External

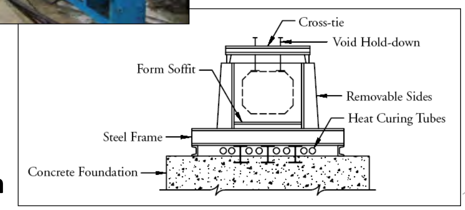
- Side forms
- Soffit
- End headers
- Adjustable forms
- Internal void forms
- Self stressing bed

Internal

- Stay-in-place
- Removable

External Forms

Girder side forms



Box beam form

Adjustable Forms

Some prestressers use adjustable forms

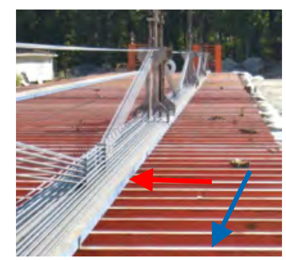
Form to adjust top flange width

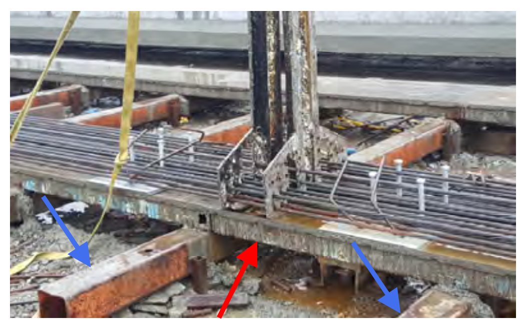
Horizontal joint(s) allows insertion of filler or haunched sections

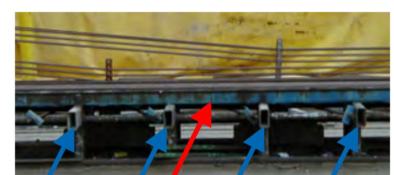
Soffit or Pallet Forms

The soffit is the form for the bottom of the girder

- Defines the width of bottom flange
- Supported by and attached to supports







End Forms

Headers are usually fabricated of steel to allow reuse

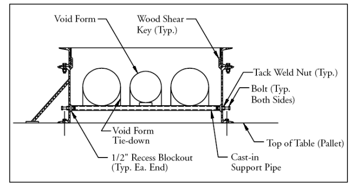
- In some cases, wood may be used if modifications are required
- Slotted for draping strands if required


Examples of headers

Bulb-tee end form (header)

Custom form required for skewed ends

Stay-In-Place Internal Forms



Voided slab form

Waxed cardboard void forms for cored slab

Polystyrene foam billet for trapezoidal box beam – also for conventional box beams

Removable Internal Forms

Placing expanded form for RR box beam

Removing retracted void form


Void form for cylinder pile

Self-Stressing Forms

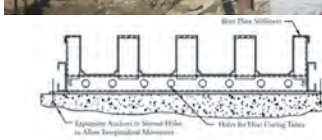
Form structure resists the pretensioning force - no abutments required

- Strand anchor plates bear on form

Double-Tee Form

- Similar to NEXT Beam

Square Piling Form

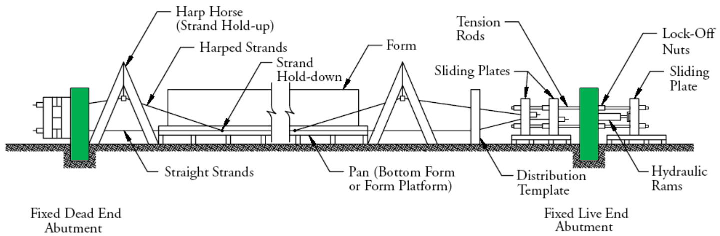



Prestressing Bed

The structure that resists the pretensioning force on the strands

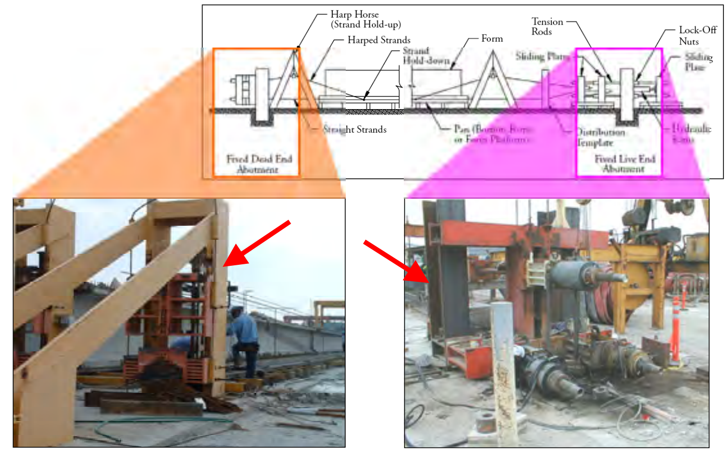
Abutment type bed – most common

- Abutments are typically fixed in foundation
- Slab may be used as a strut between the abutments
- Typical bed length: 300 – 500 ft long; can be ≤ 200 ft



Details for multi-strand tensioning are shown

Abutments



Tied

Cantilever

Strutted-Type Bed

Raised structural elements resist forces

Pile sections used as struts

Strands are in top flange for haunched pier segments of spliced girder bridges

- Struts provide reaction for strands anchored at level of strut

Strands at top of haunched segment

Strand Anchor Plates

Anchor plates span between abutments – major structural elements

- Strand pattern is set – 2 in. x 2 in. grid is typically standard
  - Caltrans standard designs use a modified grid for strands near center of section
- Assembly can usually be raised or lowered as needed

Strand Anchor Plates

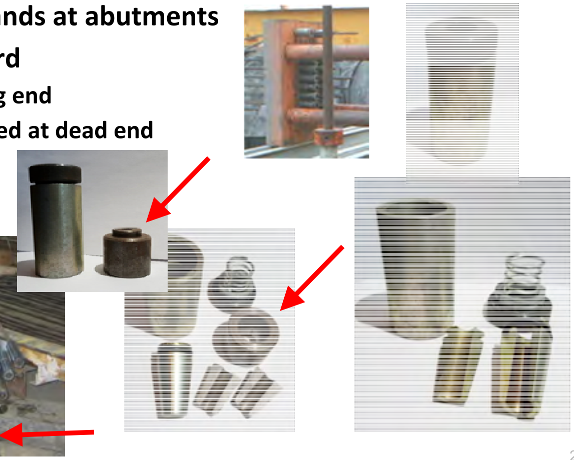
Self-stressing piling form

- Strand pattern is set using heavy end plates
- NEXT Beam is similar

Strand Anchorage

Strand chucks to anchor strands at abutments

- Reusable type is standard
  - Spring-loaded at stressing end
  - May use non-spring-loaded at dead end
- Single use chuck
- Strand splice – not used in girders



Single Strand Tensioning

Strands are tensioned from one end of bed

Single strand tensioning with long ram

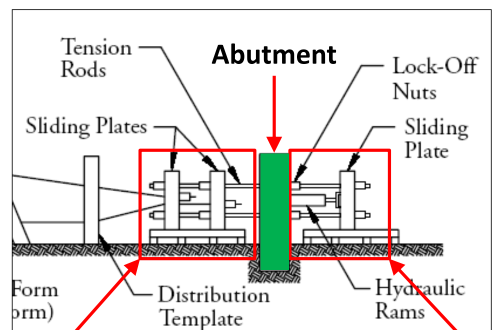
Pressure gages on pump for stressing

Pressure gage readings and elongation must agree within 5%

Typical elongation is 42.6" for 500 ft bed; 25.6" for a 300 ft bed

Elongation measurement

Multi-Strand Tensioning & Detensioning



Strand anchorages

Stressing equipment

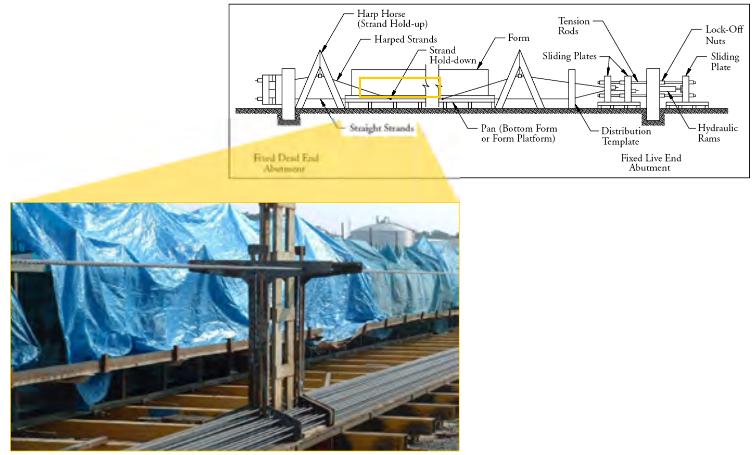
Also called "gang" tensioning

Multiple Strand Tensioning & Detensioning

Separate anchorages for top (draped) and bottom (straight) strands

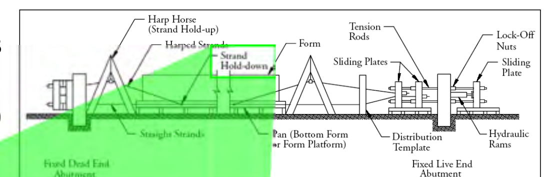
Stressing rams behind the abutments pull large rods to stress strands

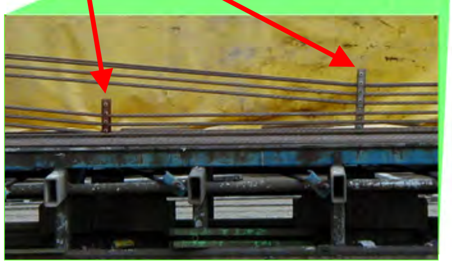
Straight Strands

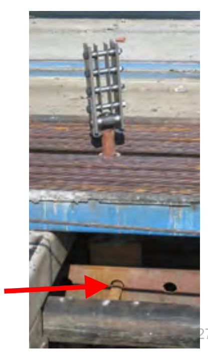


Draped Strands – Hold Down

Draped strands require strand hold down(s)



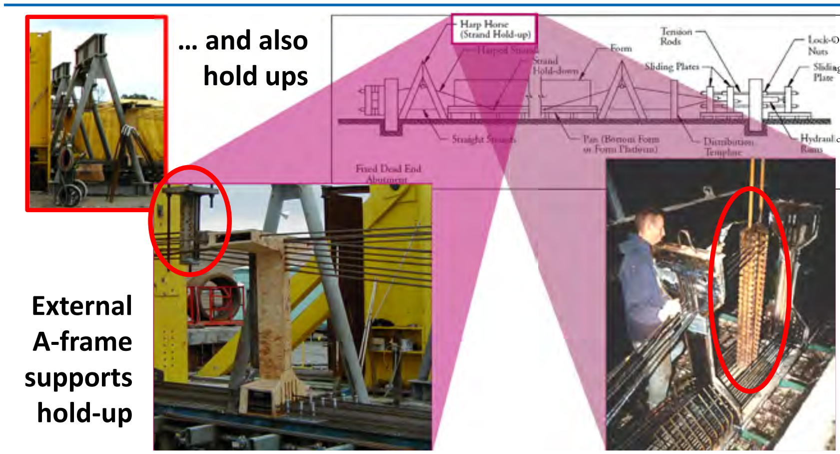




Hold down anchored to rail under bed

Draped Strands – Hold Up

… and also hold ups



External A-frame supports hold-up

Internal plate assembly supported on pallet inside bed

Draped Strands – Hold Up

Example of internal plate hold up device

In lowered position

Crane lift point

In raised position

Pin

Detail in raised position

Rollers

Stressing Strands

All strands are tensioned in 2 steps

- **Initial tension of 2000 to 4000 lbs, depending on bed length**
  - **Removes slack and seats dead end chuck**
  - **Provides reliable starting point for QC readings**
- **Remaining tension is then applied to the full initial force**
  - **For Grade 270 0.6-in.-diam. strands = 43.9 kips which is 0.75 f_{pu}**
- **Corrections may be needed for abutment movement, chuck seating, and temperature**

Draped strands will have different forces and elongations from straight strands, adding complexity to stressing operations

Debonding

Plastic sleeve or tubing prevents bond between strand and concrete

- **Option for stress control at ends of girders instead of draping**
- **Preferred over draping by most fabricators**
- **May also be used for top strands in center portion of girder**

Installation

- **Must access strands to place & seal with tape**
- **Not all strands are easily accessible**
- **Ends of sleeves must be sealed to prevent entry of concrete or paste**

Debonding

Material

- **Two-piece snap together sleeves**
  - **Easy to use**

- **Solid tube**
  - **Placed on strand as installed in bed**
  - **Not as easy to install**
- **Split sleeve (not allowed by some DOTs)**
  - **Has to be taped for full length to prevent concrete from entering sleeve**

- **Ends of all types of sheath must be sealed**
- **If sheath is not continuous, joints must also be taped**

Debonding Considerations

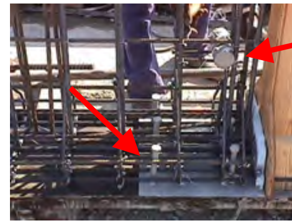
For economical design, engineers need to understand how girders are manufactured in a plant

- Provide minimum debond length required to control stresses
- Stagger terminations of debonding to avoid potential cracking
- Consider access when selecting debonded strands
  - Workers must access strands to apply and seal debonding
  - Special attention may be required where side forms are fixed and strands can only be accessed from above
- Discuss with local fabricators
  - Shifting debonded strand locations will have little or no effect on design

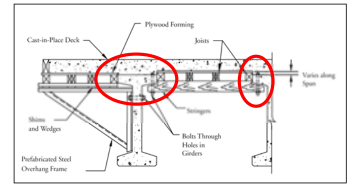
More discussion about draping and debonding in later session

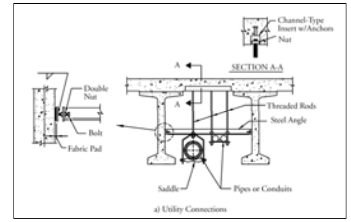
Embedments

Bearing plates and diaphragm holes



Add bars to secure diaphragm hole form





Form and pipe hangers

Quality Control

Bed setup

Cross-section dimensions

Stirrup spacing

Quality Control

Mix development and concrete testing

Slump test

Concrete strength testing

Concrete Delivery and Placement

Concrete delivered to and placed in forms

- Various methods used
- Units shown do not agitate the concrete, which is delivered by auger

Concrete delivery

Concrete placement

Concrete Delivery and Placement

Vibration is typically used to consolidate concrete

Internal vibration

External (form) vibration

Self-consolidating concrete (SCC) or high slump concrete is often used to facilitate placement, promote good consolidation, and reduce vibration requirements

- Admixtures are effective at preventing segregation of mix

Top Flange Finishes

Typically the top flange receives a raked finish with minimum amplitude of ¼ in. for composite behavior with the deck

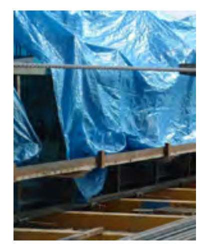
May be partial width if partial depth prestressed deck panels are used

Metal clips installed in fresh concrete for attaching metal stay-in-place deck forms

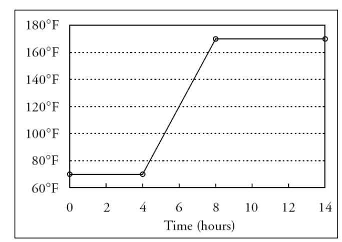
Curing

Curing is important

- Forms are typically covered to retain temperature and moisture



Curing tarps are used to retain heat for initial curing



Theoretical time-temperature curve for accelerated curing

Accelerated (elevated temperature or steam) curing may be used

Detensioning

Initial concrete strength, f'_{ci}, must be achieved before detensioning

Tarps and side forms are removed and detensioning begins as soon as possible

Single strand detensioning

- Workers simultaneously detension each strand according to pattern in shop drawings
- Strands are heated with a torch until wires relax and break – they are not cut
- Specified procedure and pattern
- Hold downs must be released to avoid damage as girders shorten

Detensioning

Gang detensioning

- Repressurize rams
- Release hardware holding load, then depressurize ram(s) slowly
- Girders will move down bed as they are detensioned
- Since girders move, hold downs must be released to avoid damage
  - May lead to high stresses in girders before strands are detensioned
  - If so, may require additional reinforcement or other measures

Detensioning

Girders camber up and the ends slide on the bed as they are detensioned

- Initial camber measurements for girders are often made while still resting on bed
- Fabricators may lift girder ends before taking camber reading to relieve any drag force at ends

Sliding can cause spalling at the ends of a girder

- Embedded bearing plates help prevent spalling

Skewed ends on bottom flange should be avoided

- With camber, points of skew will bear and drag
- Tipping and spalling is likely
- Using square ends on bottom flange is typically preferred

Finishing Girder Ends

Strands extend from girder after transfer

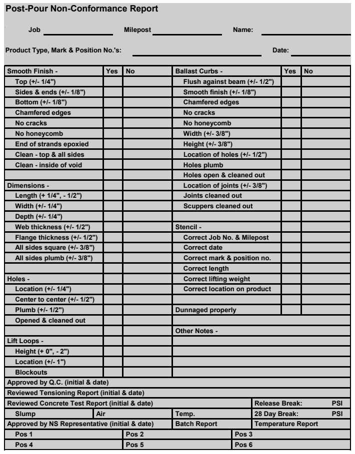
Strands are cut flush and sealed at expansion joints

Strands are cut off

Short projections are left on ends to be cast into a diaphragm

Foam recess may be used to allow for cutting and patching strands

Quality Control



Post-Pour Non-Conformance Report

Job ______ Milepost ______ Name: ______

Product Type, Mark & Position No.'s: ______ Date: ______

Smooth Finish -	Yes	No	Ballast Curbs -	Yes	No
Top (+/- 1/4")			Flush against beam (+/- 1/2")		
Sides & ends (+/- 1/8")			Smooth finish (+/- 1/8")		
Bottom (+/- 1/8")			Chamfered edges		
Chamfered edges			No cracks		
No cracks			No honeycomb		
No honeycomb			Width (+/- 3/8")		
End of strands epoxied			Height (+/- 3/8")		
Clean - top & all sides			Location of holes (+/- 1/2")		
Clean - inside of void			Holes plumb		
			Holes open & cleaned out		
Dimensions -			Location of joints (+/- 3/8")		
Length (+ 1/4", - 1/2")			Joints cleaned out		
Width (+/- 1/4")			Scuppers cleaned out		
Depth (+/- 1/4")					
Web thickness (+/- 1/2")			Stencil -		
Flange thickness (+/- 1/2")			Correct Job No. & Milepost		
All sides square (+/- 3/8")			Correct date		
All sides plumb (+/- 3/8")			Correct mark & position no.		
			Correct length		
Holes -			Correct lifting weight		
Location (+/- 1/4")			Correct location on product		
Center to center (+/- 1/2")					
Plumb (+/- 1/2")			Dunnaged properly		
Opened & cleaned out					
			Other Notes -		
Lift Loops -					
Height (+ 0", - 2")					
Location (+/- 1")					
Blockouts					

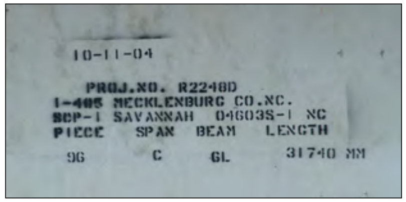
Approved by Q.C. (initial & date)

Reviewed Tensioning Report (initial & date)

Reviewed Concrete Test Report (initial & date)			Release Break: PSI
Slump	Air	Temp.	28 Day Break: PSI
Approved by NS Representative (initial & date)		Batch Report	Temperature Report

Pos 1	Pos 2	Pos 3
Pos 4	Pos 5	Pos 6

Post-pour inspection

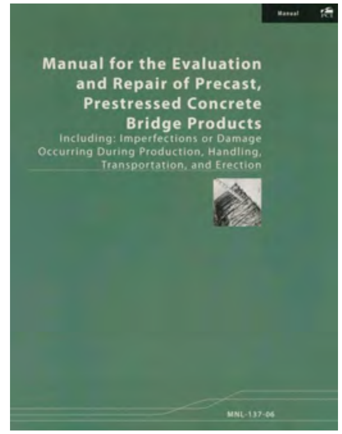


Product tracking

RFID tag

Fabrication Defects and Repairs

PCI Repair Manual (MNL 137-06)



This guide helps provide a uniform assessment and approach to fixing many defects to ensure that responses are measured, appropriate and cost-effective for the situation.

Currently being updated

Discussed in later presentation

Handling and Transportation

Plant Handling and Storage

- **Lift points**
- **Storage & stacking**

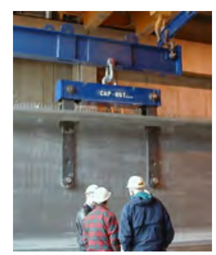
Transportation

- **Trucking**
- **Barge**
- **Rail**

Lifting and Storage

Lifting loops and other lifting devices

Typical strand loops

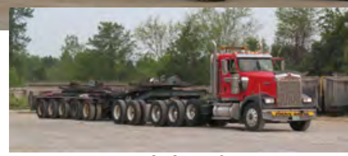


Rigid lifting devices

Sling

Lifting and Storage

Stacking & Storage



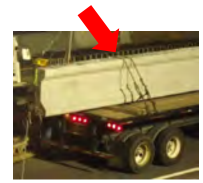
Truck loading

Shipping Considerations

Increase overhang over supports to improve stability & maneuverability

- Need to consider stress conditions
- Full f'_c is typically required before shipping

Fabricator may request holes through web or flange to secure girder to truck and avoid damage to girder



Shipping Considerations

Shipping route

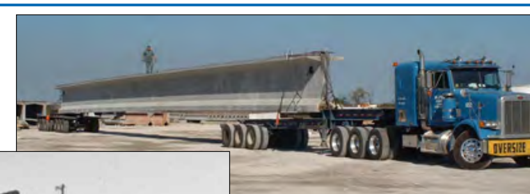
- Will load be permitted on route?
- Length of girder for curves and obstacles
- Roll stiffness of the hauling system
- Consider superelevation along route
- Access to the site

If questions – discuss with fabricator and/or hauling contractors

- Best to do this early in design to identify any potential issues

Issues related to lateral stability are discussed in later presentation

Remotely Steered Trailer



Remotely Steered Trailer – Record Length Girders

Longest single piece girder *in 2001* - NU 2800 (110 in.)

New record longest single piece girder in US

Mod WSDOT WF100G – 223 ft long at CL; add 7 ft for skew

- Uses LWC for hauling

See article in Fall 2019 *ASPIRE*

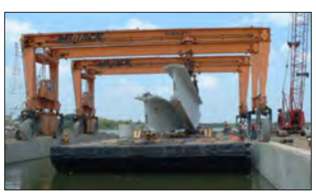
Barge & Rail

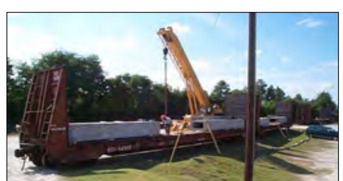
Barge loaded with beams

Barge loaded with piles

Loading box beams on railcar

Load must be balanced



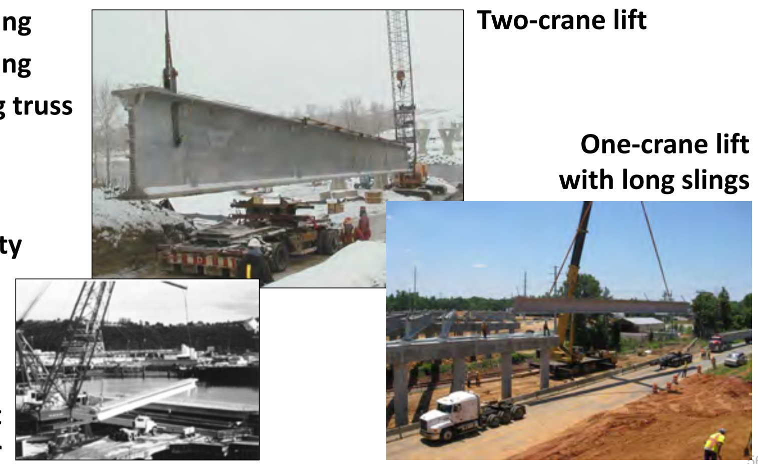


Installation

Jobsite Handling
- Crane lifting
- Launching truss
- Shoring

Connections

Lateral Stability



Two-crane lift

One-crane lift with long slings

One-crane lift with spreader bar

Launching Beam or Truss

Setting precast beam with launching beam

- Crane lifts girder from truck and sets on dolly on the launching beam
- Truck backs up to push girder across launching beam where it can be picked by crane on other end

Launching Beam or Truss

Launching beam on steroids in Oregon

Launching Beam or Truss

Placing girder on launching beam

Launching Beam or Truss

Two cranes lift girder into position on motorized carts

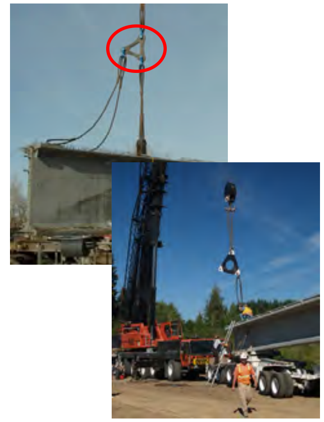
Launching Beam or Truss

Motorized carts move girder to next span for placement

Photos are from the late Keith Kaufman at Knife River PS in OR

Load Triangle

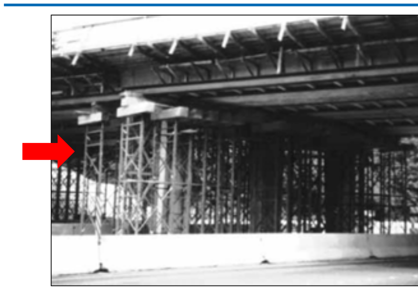
Using load triangle to pass girder between two cranes



Launching Beam or Truss

Using load triangle to pass girder between two cranes

Shoring



Shoring

Strongback

Temporary support tower for spliced girder erection

Summary

Keys to economical prestressed concrete bridges

- Understanding production of girders
- Proper design and detailing
- Local availability of products
- Repetitive use
- Open communications

Contact your local fabricators!

Prestressed Concrete Bridge Design Seminar

Session 1 – November 1, 2022

Economical Fabrication of Prestressed Girders

NEVADA DOT SAFE AND CONNECTED

Caltrans

PCI WEST

Crane Lifting

Pop quiz!!

Why are they having to use a come-along along to set this girder?

- Girder is being set with a single crane with inclined leads
- Far end of girder is higher, so it is already on the bearing
- Inclined pick on this end creates thrust

Virtual Plant Tour

Location:

Coreslab Structures, LA –

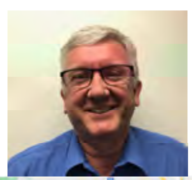
Perris, CA

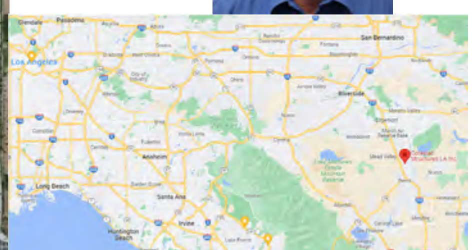
Location:

Coreslab Structures, LA –

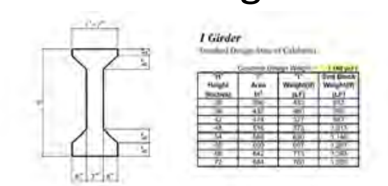
Perris, CA

Larry Bohne –
Plant Manager

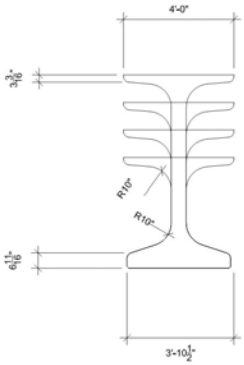




Bridge Beams – 'I' & Bulb Tee's



Bridge Beams – CA WIDE FLANGE



Wide Flange Girder

Standard Design-State of California

Concrete Design Weight = (160 pcf)

"H" Height (Inches)	"I" Area In^2	"I" Weight(lf) (LF)	End Block Weight(lf) (LF)
48	882	980	1,896
54	923	1,026	2,056
60	960	1,067	2,216
66	1001	1,112	2,376
72	1038	1,153	2,536
78	1079	1,199	2,696
84	1116	1,240	2,856

Bridge Beams

Box Girder

Height (Inches)	Width (Inches)	"BOX" Area in^2	"BOX" Weight(lf) (LF)	End Block Weight(lf) (LF)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

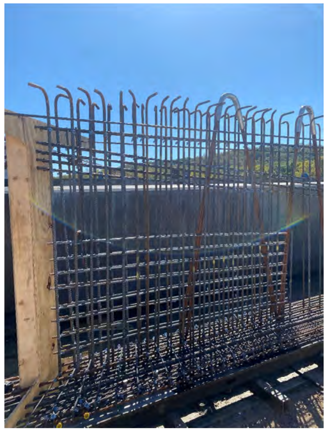
Rectangular Girder

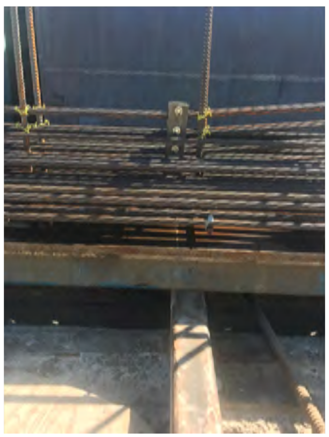
Height (Inches)	Width (Inches)	Area in^2	Weight(lf) (LF)
[illegible]	[illegible]	[illegible]	[illegible]

Prestressed Box Beams

Production

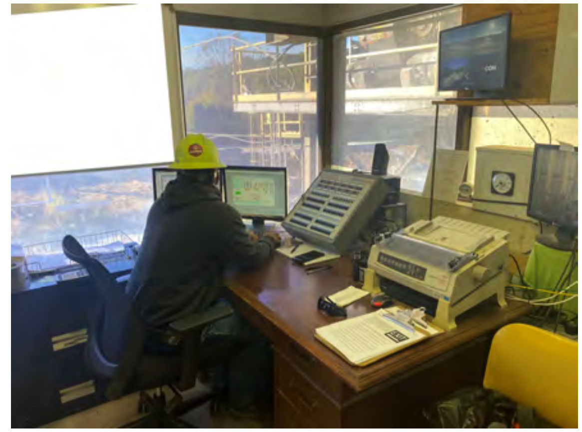
Production



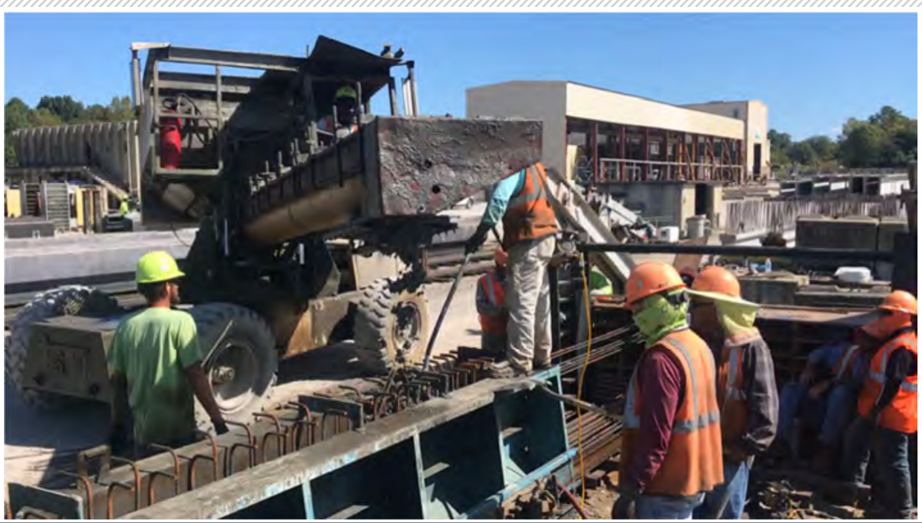

Production

Batch Plant

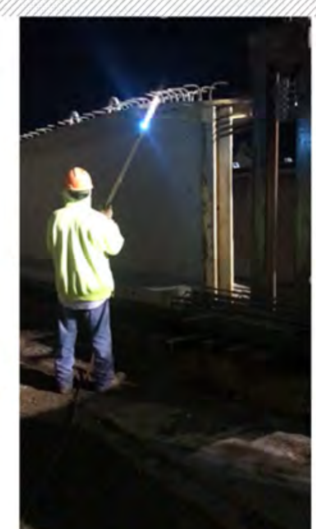


Batch Plant

Quality Control Testing of Concrete Mix



Quality Control Lab



Detensioning Process

Production - Finishing

Yard Storage

Quality Control Department

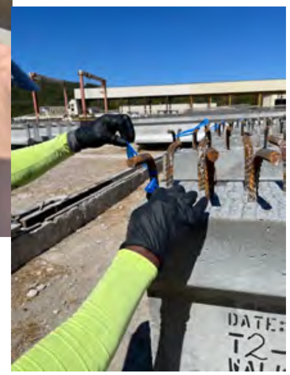
Quality Control Lab

Quality Control

Pre-Pour Check

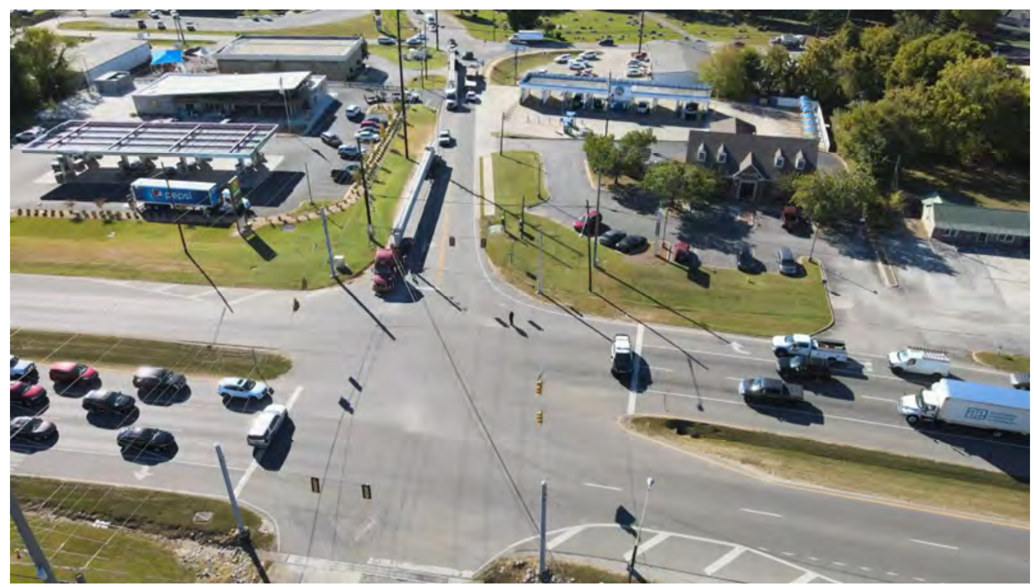
Post-Pour Check

Marking of Product



Flagging That Product Is Complete

Shipping



Acknowledgments

Thanks to fellow PCI-certified Producer Contech Engineered Solutions, LLC at their Pelham, Alabama Plant and Johnnie Hayes for the use of several images and video content in this presentation.

Virtual Plant Tour Video

Please view Coreslab Structures, LA/PCI West's virtual plant tour video that we developed with Cal Poly Pomona School of Architecture in 2020 during the height of the COVID pandemic.

View it on PCI West's YouTube Channel. Enjoy!

https://www.youtube.com/watch?v=d35Xa1buB9g

Prestressed Concrete Bridge Design Seminar

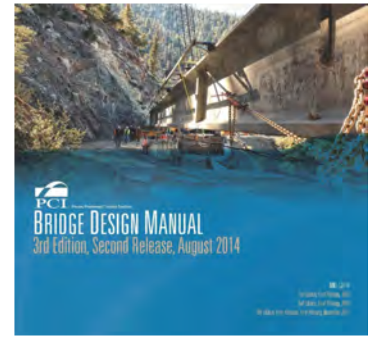
Session 1 – November 1, 2022

Economical Detailing and Design of Prestressed Concrete Girders

PCI Bridge Design Manual

Chapter 4 – Strategies for Economy
- Geometry
- Design
- Production
- Delivery and Erection

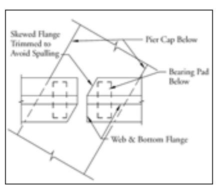
Chapter 6 – Preliminary Design
- Superstructure
- Substructure
- Preliminary design charts
- Design examples



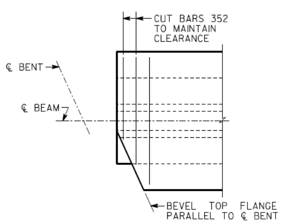
Remember, this is now *FREE* from the online PCI bookstore!

4.1 Geometry

- Span length vs. structure depth
- Splicing beams to increase spans
- Maximizing span lengths
- Member spacing
- Economy of scale
- Horizontal & vertical curves
- Skews and flares



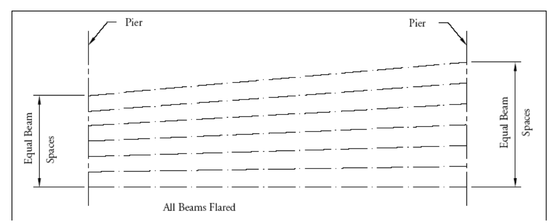
From PCI BDM



- Bottom flange remains square
- Top flange is parallel to skew

GDOT BT Std Drawing Detail for Skew

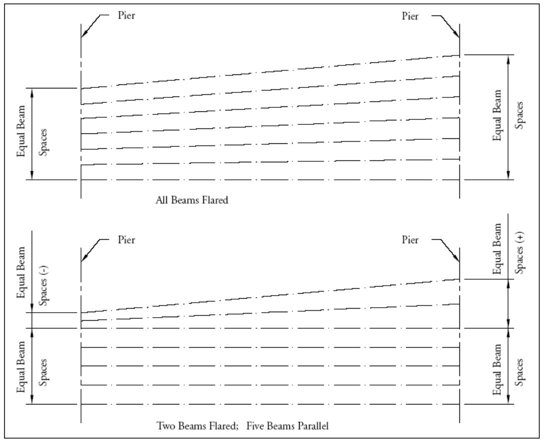
Flared Spans



All beams are different lengths

Not economical

Flared Spans



All beams are different lengths

Not economical

Almost all beams are same length

More economical

4.2.7 Nonprestressed Reinforcement

Detailing

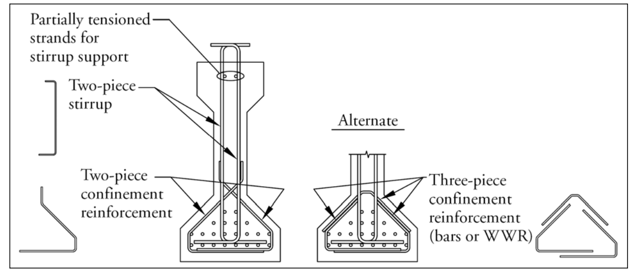


Figure 4.2.7.1-1 Multi-Piece Reinforcement

Two-piece top flange reinforcement

Allows adjustment, but nearly 2x steel

- **More pieces require more labor to install**
- **Laps require more steel, but allow adjustment for bend tolerances**
- **One-piece bars not practical - require threading strands through them**

4.2.7 Nonprestressed Reinforcement

Welded wire reinforcement (WWR)

- **Up to #5 bar equivalent (D31)**
- **WWR has 75 to 80 ksi yield strength**
- **Bars can be added to WWR if needed**

Using WWR can save labor and material costs, especially if higher strength is allowed

- **Standardized details allow use of the same panels on different projects**

Caltrans standards provide alternate details for WWR

Photos from Insteel bridge brochure @ www.insteel.com

Detailing Considerations

Use Same Strand Pattern in Span

Girders are more economical if fabricator can make more girders in same pour

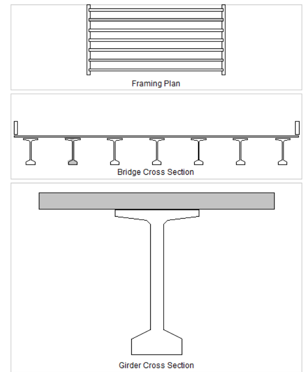
- **For designers, it appears that saving a few strands would save money on a project**
- **However, adding a few strands to make strand patterns the same for a span or multiple spans will save much more money**

Using the fewest strands (default design) for every girder does <u>not</u> necessarily give the most economical solution

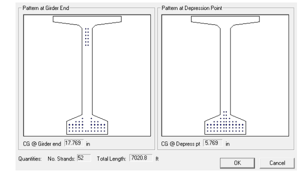
Example 1: Use Same Strand Pattern in Span

L = 135 ft; Mod BT-74

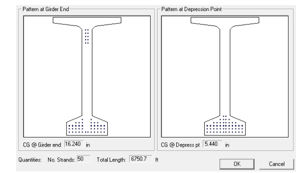
Spacing = 10 ft; width = 68 ft



Original designs



Interior: 52 strands, 12 draped



Exterior: 50 strands, 10 draped

Example 1: Use Same Strand Pattern in Span

- **Using 52 strands for both girders works well**
  - **Improved (reduced) stress at transfer at ends**
  - **Improved (reduced) service stress at midspan**
  - **Cambers were closer**

Effect on design:

	Original	Original (Compare)	Revised (Compare)	Limiting
Position	Exterior	Interior	Interior	Stresses
No. of strands	52	50	52	--
No. of draped strands	12	10	12	--
Top stress @ transfer - end (ksi)	0.126	-0.042	0.126	-0.200
Bot. stress @ transfer - end (ksi)	4.379	4.388	4.379	4.550
Bot. stress @ service – midsp (ksi)	-0.527	-0.539	-0.421	-0.554
Total camber at midspan (in.)	+2.87	+2.52	+2.63	--

Example 1: Use Same Strand Pattern in Span

Strand requirements:

- **Original design: 2 Exterior @ 52 + 5 Interior @ 50 = 354 strands**
- **Revised design: All 7 @ 52 = 364 strands, or 2.8% more than original**

If only one or few spans with these girder, could be better to have all girders with the same strand pattern

If there are <u>many</u> spans of the same girders, could make original designs work with the right erection schedule by casting exterior girders together

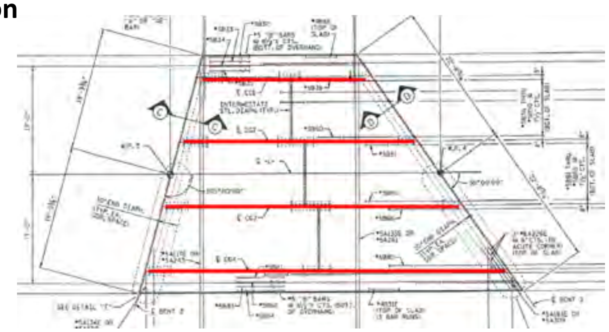
Benefits of using same strand patterns

- **Flexibility in casting girders with potential savings in time & material**
- **Also depends on length of beds available for fabricator**

Example 2: Using Same Strands in Span

One highly trapezoidal span in six span bridge

- Type III girders for this span; other spans in bridge were BTs
- 4 girders in cross-section
- Lengths varied from about 27.5 ft to 56.8 ft
- Number of strands varied from 10 to 20



Example 2: Using Same Strands in Span

Options for fabricator

- Option 1: Cast each girder separately in a 300 ft bed
  - Strands required: 325 ft x (10 + 12 + 16 + 20) = 18,850 ft
  - 4 pours, each taking 1 or 2 days = over a week of bed time
- Option 2: Cast all 4 girders in bed and use full-length debonding to disable extra strands
  - Strands required: 325 ft x 20 = 6,600 ft (34% of Option 1)
  - 1 pour taking 1 or 2 days, or a quarter of the bed time
- Option 3: Check designs to see if 20 strands could be used in all 4 beams, or possibly use 2 strand patterns, so only 2 pours
  - Requires redesign, and approval may not be certain

Example 2: Using Same Strands in Span

Option 2 was preferred for fabricator as least expensive and most efficient (1 pour using full length debonded strands as needed)

- Fabricator had to bid job using Option 1 (4 pours)
  - DOT allowed fabricator to use full-length debonding when proposed after award
  - Savings were significant, and appreciated, but not shared with DOT as would have happened if plan notes had allowed full length debonding
- Savings in strand alone was 12,250 ft
  - At about $0.85/ft for installed strand = $10,412
  - Also significant savings in labor and bed utilization for fabricator

Full-length debonding is allowed by note and details on NCDOT standard plans for cored slabs and box beams

Placement of Hold Downs for Draped Strands

Design programs often use a fraction of the span length to location hold downs

- Caltrans standard details show location at 0.33L to 0.40 L
- Using a fixed distance, such as 5 ft each side of midspan, may be preferred by fabricators

Girders are detailed with a single hold down on each side, but may need to be fabricated with more hold downs – very little effect on the design

Hold down locations are typically shifted as hold down anchorage points are only available at fixed points along the bed

Using one hold down is generally not possible since force is twice that of two hold downs and hardware may not be able to resist the force

Reinforcing Steel Details

Reinforcement details should be consistent

Design/build projects with a number of bridges can come in with significantly different designs for the same project

- **Design team should coordinate and work to make designs consistent throughout project for greater efficiency**

Reinforcing Steel Details

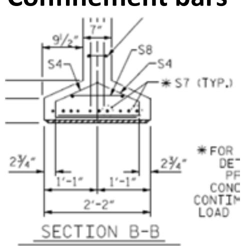
Consider actual bar diameter and bend radius when laying out details

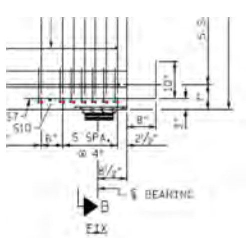
- **Make sure that cover will be available, especially considering bar bends and actual bar diameter**
- **Make sure that reinforcement will not conflict with other bars or strands or embedments, diaphragm holes, etc.**
- **Consider bar bending tolerances as not all bars are bent precisely to the dimensions in the plans**

Reinforcing Steel Details

Consider actual dimensions and details of rebar

- **Confinement bars**





Really 2 dots per pair – can make it tough to place concrete above bearing plate

If stirrups are detailed with bottom hooks, even more bars will be in this congested area

LRFD Art. 5.10.10.2 only requires confinement steel for 1.5*d* from end of girder with spacing at no more than 6 in.

Reinforcing Steel Details

More is not always better!

- **Too much vertical steel in the end of a beam increases the potential for problems with consolidation of concrete**
  - **It also increases cost of reinforcement and labor**

Detail to Accommodate Tolerances

Girder fabrication and erection tolerances must also be considered

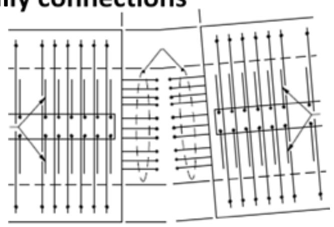
- **Girders cannot be set precisely; length and other dimensions can vary**

Provide tolerance in details

- **Example: steel diaphragms must be adjustable for provide tolerance for hole placement and girder erection**

Consider actual fit up of rebar details – especially connections

- **Example: continuity reinforcement details with angle change**
- **Draw details of connections using actual dimensions to reveal potential problems**



Prestressed Concrete Bridge Design Seminar

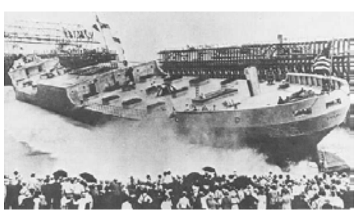
Session 1 – November 1, 2022

Economical Detailing and Design of Prestressed Concrete Girders

Lightweight Concrete

Structural lightweight aggregate (LWA) has been commercially manufactured in the US since 1920 – so it is not a new material

It was immediately used to produce structural lightweight concrete (LWC)



USS Selma 1918

San Francisco Oakland Bay Bridge 1936

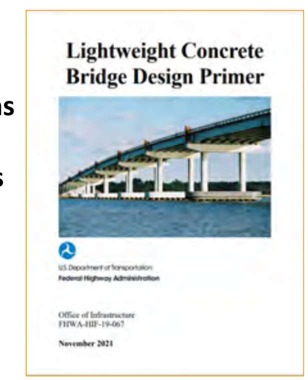
- **Obvious benefit was reduced density**
- **It was also discovered that LWC was very durable**

Lightweight Concrete

***Lightweight Concrete Bridge Design Primer* from FHWA is now available.**

Can be downloaded from the FHWA website:
https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf

- **Highlights benefits of LWC in various applications and covers the primary design and construction topics needed to design LWC highway structures**
- **Discusses recent changes in the *AASHTO LRFD Bridge Design Specifications* pertaining to LWC**
- **Includes limited guidance on the use of prewetted LWA for internal curing**



San Francisco-Oakland Bay Bridge, CA

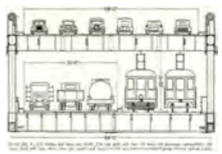
Upper deck of suspension spans across the Bay was built in 1936 using "all-LWC" with a unit weight of 95 pcf

- LWC saved 25 psf ⇒ 31,600 kips ⇒ $3 million of $40 million when completed in 1936

Lower deck reconfiguration in 1958 also used all LWC

Both LWC decks are still in service today

- Have been protected with wearing surfaces



I-5 over Skagit River - Mt Vernon, WA

Span replaced using LWC deck girders

- 65" deep deck girders with 6.5 ft wide top flange
- Girder length = 162 ft
- Girder weight = 84 tons

LWC properties for girders

- Design density of LWC = 122 pcf
- Design compressive strength = 9,000 psi
  - Actual design compressive strength = 10,600 psi

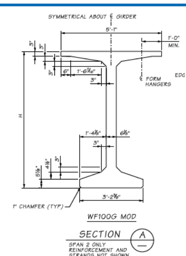
LWC used for girders cost 2x usual NWC per CY

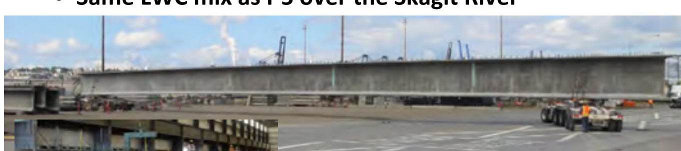
- But avoided costs and delays for seismic reanalysis and design of piers

Portland Ave/Puyallup River - Tacoma, WA

New US record for the longest single piece PS girder

- 223 ft long – plus severe skews (add 7 ft)
- WF100G Mod – 8'-4" tall; 5'-1" wide top flange
- LWC required to be able to truck girder to site
  - Same LWC mix as I-5 over the Skagit River



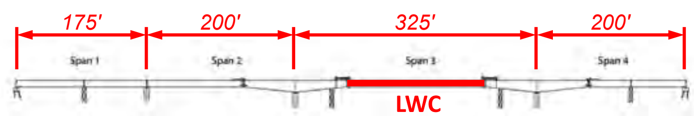


See *ASPIRE* Magazine – Fall 2019 Issue

Route 22 over the KY River - Gratz, KY

PS concrete spliced girder proposed as alternate to steel girder design

- 4 spans with 325 ft main span - record for US (2010)
- LWC used for 185 ft long drop in girders – erected 2 at once



From *ASPIRE* Magazine – Winter 2011 Issue

Benicia-Martinez Bridge, CA

I-680 over the Carquinez Strait north of San Francisco (2008)

Cast-in-place box girder

- 82 ft (25m) wide deck
- 658 ft (201m) max. spans

LWC was used for the entire segmental box girder cross-section

- LWC used for full length of 6500 ft bridge except for pier segments
- Reduced seismic forces, foundations & cost

If research on LWC ductility had been completed at the time of design, the bridge would probably have been LWC from the top of the footing

Longest Segmental Concrete Box Girder Spans in World

LWC was used for up to 75% of main span in highlighted bridges, all in Norway

	No.	Project Name	Country	Span (m)	Year Built
	1	Stolmasundet bro	Norway	301	1998
LWC	2	Raftsundet, Lofoten	Norway	298	1998
	2	Sundoya	Norway	298	2003
	3	Humen, Pearl River	China	270	1997
	4	Varodd bro, Kristiansand	Norway	260	1993
	5	Gateway bridge, Brisbane	Australia	260	1986
	6	Skye bridge	England	250	1995
	7	Ponte San Joao, Porto	Portugal	250	1991
	8	Talübervergang Schottwein	Austria	250	1989
	9	Northumberland Strait Crossing	Canada	250	1997
	10	Chevire Viaduct, Nantes	France	242	1991
	11	Norddalsfjord bro	Norway	231	1987
LWC	12	Stovset bro	Norway	220	1993

From NRS BRIDGE CONSTRUCTION EQUIPMENT & ENR (Nov. 2003)

Stolma Bridge, Hordaland, Norway

World record span for its type when completed in 1998

Cast-in-place single-cell segmental box

- Center span is 301 m (988 ft)
- Side spans are 94 and 72 m (308 and 236 ft)
- LWC (LC60) used in middle 184 m (276 ft) of main span

LWC was used to achieve better balance between main and side spans

NordHordland Bridge, Hordaland, Norway

LWC was used for superstructure on the 535 ft cable-stayed main span completed in 1994

- LWC saved nearly 1% of total contract cost
- Reduced cost of stays and size of hold-down structure

LWC also used for pontoons for floating bridge

- LWC saved 3 to 7% of cost because of smaller pontoons
- Reduced wave forces ⇒ reduced load on structure

A few other cable-stayed bridges have used LWC

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