Prestressed Concrete Bridge Design Seminar

Session 1 – April 13, 2021

2b. Economical Detailing and Design of Prestressed Concrete Girders

PCI Mid-Atlantic
A Chapter of the Precast/Prestressed Concrete Institute

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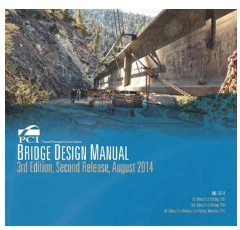
PCI Bridge Design Manual

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

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



We encourage you to explore these chapters in the *PCI Bridge Design Manual* and see what you can learn!

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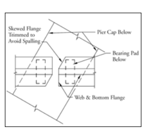
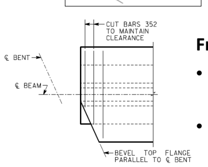
4.1 Geometry

- 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



From GDOT BT Std Dwg
- Bottom flange remains square
- Trim top flange to edge of web

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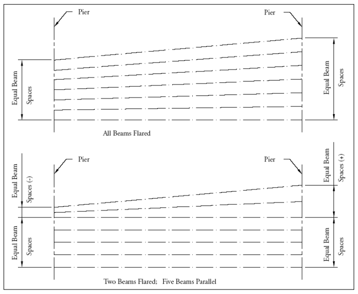
Flared Spans



All beams are different lengths

Not economical

Almost all beams are same length

More economical

4.2.7 Nonprestressed Reinforcement

Detailing

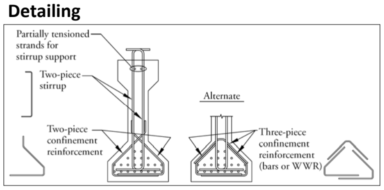


Figure 4.2.7.1-1 Multi-Piece Reinforcement

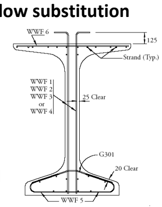
Two-piece top flange reinforcement

- **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)**
- **75 to 80 ksi yield strength (LRFD)**
- **Cross-wires provide anchorage**
- **Some DOTs only allow substitution using 60 ksi**
- **Using WWR can save labor & material costs, especially if higher strength is allowed to be used**



Photos from Insteel bridge brochure @ www.insteel.com

Preliminary Design Charts

Chapter 6 in the *PCI Bridge Design Manual* has preliminary design charts

- AASHTO cored slabs, box beams
- AASHTO girders and PCI BTs
- Some other sections

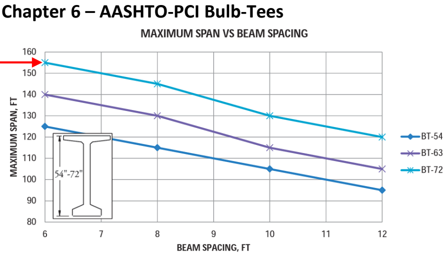
These are a good place to start to get an idea of a potential girder type

- Check assumptions before you use them
- They will get you in the neighborhood

Preliminary Design Charts

PCI BDM Chapter 6 – AASHTO-PCI Bulb-Tees

Max span for BT-72 is 155 ft



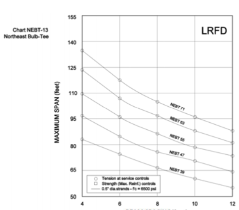
Span chart for each family of sections

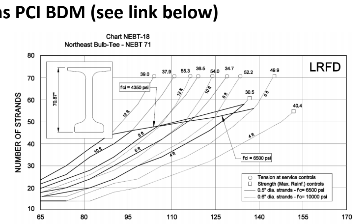
Also charts for no. of strands & table of design results

Preliminary Design Charts

Preliminary design charts are also available for NEBTs; PCEF BTs similar

- Charts have same format as PCI BDM (see link below)





https://www.pci.org/PCI_Docs/PCI_Northeast/Technical_Resources/Bridge/2013_LRFD_NEBT_Preliminary_Load_charts_US_units-1.pdf

Use Same Strand Patterns if Possible

Using the fewest strands in every girder does <u>not</u> necessarily give the most economical solution

Girders are more economical if fabricator can make more girders in the bed at the same time

- It may appear that saving a few strands would save money on a project
- But girders with different strand patterns must be cast separately
- However, adding a few strands to make strand patterns the same for a span or multiple spans will save much more money

Check with local fabricators!

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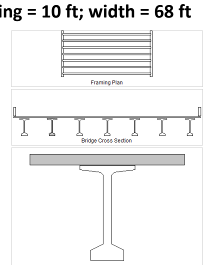
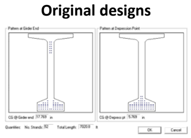
Example 1: Use Same Strand Pattern in Span

L = 135 ft; Mod BT-74

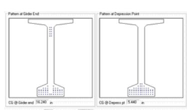
Spacing = 10 ft; width = 68 ft



Original designs



Exterior: 52 strands, 12 draped (2 girders)



Interior: 50 strands, 10 draped (5 girders)

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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
  - Computed cambers were closer

Effect on design:

	Original	Original	Revised	Limiting
		Compare	Compare	
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	--

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Example 1: Use Same Strand Pattern in Span

Strand requirements:

- **Original: 2 Ext. with 52 + 5 Int. with 50 = 354 strands**
- **Revised: 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 – cast exterior girders together

Benefits using same strand patterns

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

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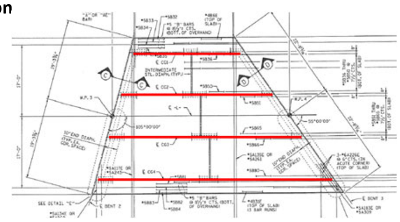
Example 2: Using Same Strands in Span

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**



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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: Check designs to see if 20 strands could be used in all 4 beams, or possibly use 2 strand patterns, so only 1 or 2 pours**
  - **Requires redesign, and outcome is not certain**
- **Option 3: Cast all 4 girders in bed and use <u>full-length debonding</u> to disable extra strands**
  - **Total strands required: 325 ft x 20 = 6,600 ft (34% of Option 1)**
  - **1 pour taking 1 or 2 days; about a third of the bed time**

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Example 2: Using Same Strands in Span

Option 3 was preferred by fabricator as least expensive and most efficient (1 pour using full length debonded strands as needed)

- But 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 detailed as <u>option</u> on standard plans for at least one DOT (NCDOT) for cored slabs and box beams

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Questions?

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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

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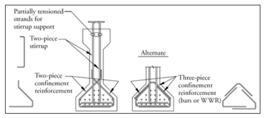
Reinforcing Steel Details

Must bear in mind that strands run from one abutment to the other

- **If a closed confinement bar is detailed, strands must be threaded through it**

Simple, efficient details are preferred, if possible

- **Fewer pieces are typically better**
- **Details that allow for tolerances are also important**
- **Bar laps provide adjustment, but more steel, and more pieces mean more labor**



Consult with fabricator!

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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**
- **Make sure that reinforcement will not conflict with other bars or strands or embedments (diaphragm holes)**
- **Consider bar bending tolerances as not all bars are bent precisely to the dimensions in the plans**

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Reinforcing Steel Details

More is <u>not</u> always better!

- **Too much vertical steel in the end of a beam will cause problems with consolidation of concrete**
  - **It also increases cost of reinforcement and labor**
- **Confinement bars for full length of girder is not required by the LRFD Specifications**
  - **Again, added bars increase cost of reinforcement and labor**
- **Should also consider actual bar sizes and bends to evaluate the effect of extra steel**

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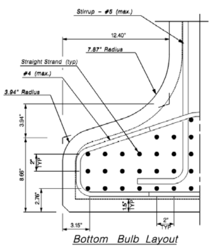
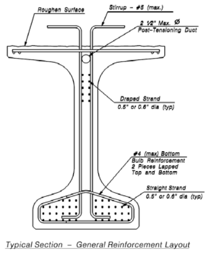
Reinforcing Steel Details

Consider actual dimensions and details of rebar

- New England BT bottom flange reinforcement





Using 2-piece confinement bars is a good, simple detail

Stirrups detailed with bottom hooks on top of bottom row of strands is helpful

WWR for top flange reinforcement is a good idea to simplify install

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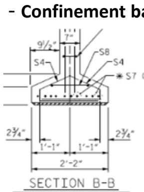
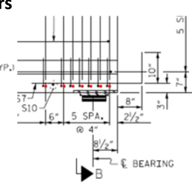
Reinforcing Steel Details

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 that cross under the web, 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.

- **Matching the spacing of stirrups is <u>not</u> required**

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Stirrup Details

Accommodating camber by varying stirrup projections

- Some designers provide many bar lengths (and marks) to follow anticipated girder camber
  - Some have provided bars with as little as 1/4 in. difference between bar marks
- This is a major problem for fabricators
  - Tolerance in bending stirrups is typically ½ to 1 in., so increments less than that can be lost in the variation in bar bending
- Should only need a few bar marks
  - Allow bar to move within the core of the slab
  - Some details allow bar to be moved in girder to achieve increments of projection

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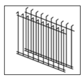
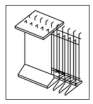
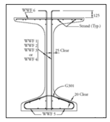
Reinforcing Steel Details

- Top strands are often provided to support stirrups and top flange reinforcement
  - Often partially tensioned to reduce sag
  - They do not significantly affect stresses
- Welded wire reinforcement panels for end regions of girder has great potential for cost savings
  - Must be standardized to be economical
  - Could then be ordered in bulk
  - FDOT has such details for FIBs
  - GDOT allows substitution of WWR
    - Design yield strength limited to 60 ksi







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Concrete Unit Weight with Reinforcement

LRFD Table 3.5.1-1 – Unit Weights

Concrete	Lightweight	0.110
	Sand-Lightweight	0.120
	Normal Weight with $f'_c \leq 5.0$ ksi	0.145
	Normal Weight with $5.0 < f'_c \leq 15.0$ ksi	$0.140 + 0.001 f'_c$

- For plain concrete
  - 0.145 kcf applies up to f'_c = 5 ksi
  - For f'_c > 5 ksi, use expression: Add 0.001 kcf per 1 ksi increase in f'_c
    - Should use 150 pcf for 10 ksi concrete
    - Could be more or less depending on aggregate source
  - Use unit weight (plain concrete) for computing E_c

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Concrete Unit Weight with Reinforcement

- Allowance for weight of reinforcement in dead load calculations
  - Add 5 pcf to concrete weight for steel (B&SDM 3.4.1.1.4 a))
  - Should check strand & rebar contribution for heavily reinforced members
  - May be as much as 10 pcf for bulb-tees
  - Affects both design and shipping loads
  - Should not use for computing E_c
- Example – Design of heavily reinforced Mod BT-54
  - 35 plf rebar + 40–0.6 in. diam. strands = 30 plf
  - Adds 9.2 plf to concrete unit weight of 145 pcf
  - So effective unit weight of reinforced concrete is 154.2 pcf – not 150 pcf

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Lightweight Concrete

Can use lightweight concrete for girders (and decks)

- Reduce weight for design efficiency, handling and transport
- GDOT girder demonstration project
  - 120 pcf for 10 ksi concrete used on I-85 ramp bridge
- VDOT is using for pretensioned girders and decks on several projects
  - Several research reports from VTRC are available
  - Has been used for spliced post-tensioned girder project
- WSDOT used LWC for longest single-piece girder in US
  - 223 ft long, with w_c = 125 pcf, f'_{ci} = 8.4 ksi, f'_c = 10 ksi – see *ASPIRE* Fall 2019
  - LWC used for transportation

Typical design use 120 to 125 pcf for fresh and equilibrium densities with f'_c up to 10 ksi for girder concrete

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Construction Tolerances

Girders cannot be set precisely in place – there will be some variation

Girder fabrication tolerances must also be considered

Provide tolerance in details

- For example – steel diaphragms must be adjustable for provide tolerance for hole placement and girder erection

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