Prestressed Concrete Bridge Design Seminar

Session 2 – April 20, 2021

Design 2 – Girder Sections & Camber

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

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Standard Girder Sections

- First standard girder sections developed in 1950s
  - AASHTO/PCI standard shapes developed to give national standard
  - Standard shapes needed for efficiency in design and fabrication
- Later, the PCI bulb-tee girders were standardized
- States also developed their own shapes
- In 1990s, some new shapes were developed
  - Larger bottom flanges to allow more strands
  - Wider top flanges to improve stability
  - PCI Northeast developed a regional standard Mid-Atlantic states took that shape and modified it removing curves

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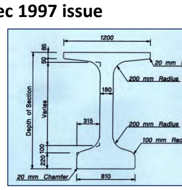
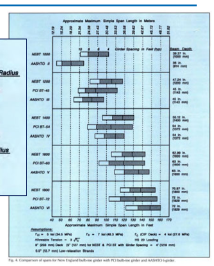
Standard Girder Sections

PCI Journal article in Nov-Dec 1997 issue





Developed in metric units

Curves instead of fillets

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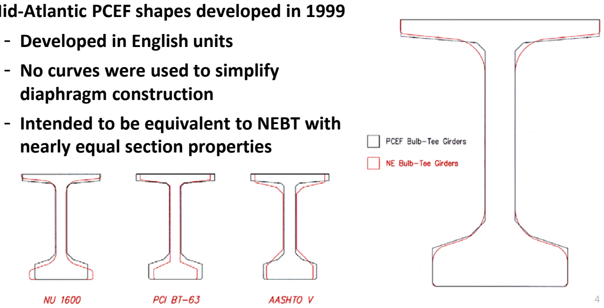
Standard Girder Sections

Mid-Atlantic PCEF shapes developed in 1999

- Developed in English units
- No curves were used to simplify diaphragm construction
- Intended to be equivalent to NEBT with nearly equal section properties



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Standard Girder Sections

Compare NEBT and PCEF section properties - from 1999 PCEF document

	Depth	Area	Centroid to Bottom	Moment of Inertia	Weight @ 150 lb/ft³
	in.	in.²	in.	in.⁴ x 10³	lb/ft
XB 39 47	39.0	754.7	18.78	148.1	786
NEBT 1000	39.4	745.6	19.02	149.2	777
% Difference	1.0%	-1.2%	1.3%	0.7%	-1.2%
XB 55 47	55.0	866.7	26.07	355.8	903
NEBT 1400	55.1	857.2	26.27	352.0	893
% Difference	0.2%	-1.1%	0.8%	-1.1%	-1.1%
XB 71 47	71.0	978.7	33.51	673.6	1020
NEBT 1800	70.9	968.8	33.67	660.4	1009
% Difference	-0.1%	-1.0%	0.5%	-2.0%	-1.1%

Note: % Difference is computed as (NEBT - PCEF) / NEBT x 100%

- Metric unit conversion affects the comparison
- Section property differences are small: +1.0% to -2.0%
- Section properties vary slightly from NEBT values given in NYSDOT standard drawing BD-PC15E

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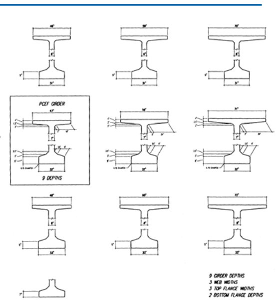
Standard Girder Sections

Proposed Mid-Atlantic PCEF shapes included variable dimensions

- 9 girder depths
- 3 web widths: 6, 7, and 8 in.
- 3 top flange widths: 48, 60, and 72 in.
- 2 bottom flange depths: 7 and 9 in.
- Resulted in a family of 162 shapes
  - A bit over-ambitious
  - DOTs in region adopted limited combinations of dimensions



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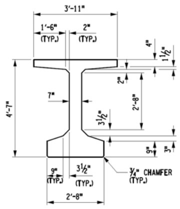
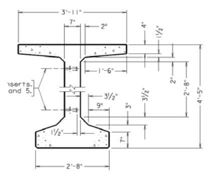
Standard Girder Sections

Examples of PCEF sections adopted by DOTs

- **7 in. web**
- **3’-11” top flange**
- **2’-8” bottom flange**
- **Bottom flange thickness varies, which affects depth**
  - **NYSDOT: 9” flange with 55” depth**
  - **VDOT: 7” flange with 53” depth**
  - **NEBT has 9” flange**



PCEF-55
NYSDOT



PCBT-53S
VDOT

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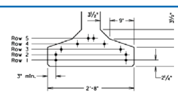
Standard Girder Sections

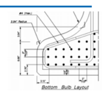
Reinforcement details also vary

- **Distance to bottom row of strands**
- **Stirrup details**
- **Confinement bar details**

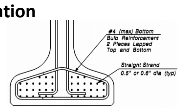
Standardization of details between DOTs is preferred for efficient design and fabrication



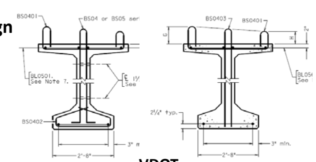
VDOT



NEBT



NEBT



VDOT

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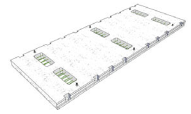
Other Standard Bridge Sections

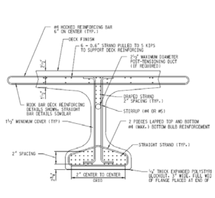
All of these are very good for ABC projects because the deck is precast in the plant

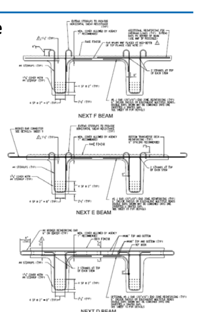
NEXT beams – 3 types

NE decked bulb tee

Full-depth precast deck







***Standard details and more info on PCINE website:* [*www.pcine.org*](http://www.pcine.org)**

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Camber

For prestressed concrete girders, cambers are estimated

Camber estimating methods

- Multiplier Methods
- Improved Multiplier Methods – Factors in estimates of prestress loss
- Detailed Analytical Methods – Numerical, time-step evaluation

Many factors affect the actual camber – see hidden slides

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Factors Affecting Camber

Prestress

- Total no. of strands = Force (*P*)
- Strand pattern (*e*)
- Method for stress control (draped or straight with debonding)

Geometry

- Beam length
- Support locations
- Girder type → section properties
- Girder spacing and deck dimensions

These factors are well known and can be controlled

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Factors Affecting Camber

Materials properties – Specified and actual

- f'_{ci} and f'_c
- E_{ci} and E_c
- w_c of girder
- Prestress losses

Fabrication & construction timing

- Age at transfer of prestress
- Age at erection

Environmental conditions

These factors are based on estimates and some cannot be controlled

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Multiplier Method

Most popular method in current practice

Developed by Martin (*PCI Journal* article in 1977)

Straightforward calculations

Apply multipliers to each component of elastic deflection to predict long-term behavior

- Prestress uplift
- Self-weight deflections

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Assumptions for Elastic Deflections

Use appropriate concrete properties, effective prestress for stage being considered

- Use E_{ci} and f_{pi} for initial camber
- Use E_c at ages > 28 days (final after losses)

Girder remains uncracked at all load stages

- Gross (uncracked) section properties
- Transformed deck
- Transformed prestressing strand may be included

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Initial Camber of Bare Beam

Sum of upward effect of PS and downward effect of girder deadload

$$(\Delta_{\max})_{rel} = (\Delta_{ps})_{rel} \uparrow + (\Delta_{gdl})_{rel} \downarrow$$

Factors affecting estimated initial camber

- **Age at release (usually about 18 hours)**
- **Concrete properties**
- **Curing conditions, concrete temperature, and ambient conditions**
- **Prestress losses**
- **Storage and support conditions**

Equations available (hidden slides) for computing camber due to PS

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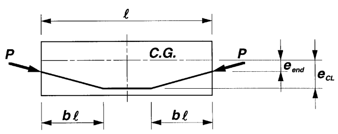
Elastic Deflections at Midspan

See PCI BDM and PCI Handbook

- **Dead load – use standard equation**
- **Two-point draped strands**

$$\Delta_{\max} = \frac{Pl^2}{24EI}\left[3e_{CL} - (e_{CL} - e_{end})4b^2\right]$$



- **There is also an equation for single point drape**

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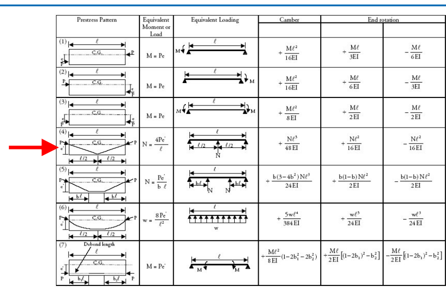
BDM Table 8.7-1 Camber & Rotations



Prestress Pattern	Equivalent Moment or Load	Equivalent Loading	Camber	End rotation	
(1)	$M = Pe$		$+\frac{M\ell^2}{16EI}$	$+\frac{M\ell}{3EI}$	$-\frac{M\ell}{6EI}$
(2)	$M = Pe$		$+\frac{M\ell^2}{16EI}$	$+\frac{M\ell}{6EI}$	$-\frac{M\ell}{3EI}$
(3)	$M = Pe$		$+\frac{M\ell^2}{8EI}$	$+\frac{M\ell}{2EI}$	$-\frac{M\ell}{2EI}$
(4)	$N = \frac{4Pe'}{\ell}$		$+\frac{N\ell^3}{48EI}$	$+\frac{N\ell^2}{16EI}$	$-\frac{N\ell^2}{16EI}$
(5)	$N = \frac{Pe'}{b\ \ell}$		$+\frac{b(3-4b^2)N\ell^3}{24EI}$	$+\frac{b(1-b)N\ell^2}{2EI}$	$-\frac{b(1-b)N\ell^2}{2EI}$
(6)	$w = \frac{8Pe'}{\ell^2}$		$+\frac{5w\ell^4}{384EI}$	$+\frac{w\ell^3}{24EI}$	$-\frac{w\ell^3}{24EI}$
(7) Debond length	$M = Pe'$		$+\frac{M\ell^2}{8EI}(1-2b_1^2-2b_2^2)$	$+\frac{M\ell}{2EI}\left[(1-2b_1)^2-b_2^2\right]$	$-\frac{M\ell}{2EI}\left[(1-2b_1)^2-b_2^2\right]$

Use superposition to combine different patterns

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Deflections at Other Locations

General equations

Moment-Area Method

Conjugate Beam Method

- **Load beam with *M/EI* diagram**
- **Moments in conjugate beam correspond to deflections**
- **Use when debonding present**
- **Method can be used for any moment diagram resulting from prestress or loads**

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Final Deflection of Structure

Sum of all effects, with only PS acting upward

$$(\Delta_{\max})_{fin} = (\Delta_{ps})_{fin} \uparrow + (\Delta_{gdl})_{fin} \downarrow + (\Delta_{ddl})_{fin} \downarrow + (\Delta_{ncdl})_{fin} \downarrow + (\Delta_{sdl})_{fin} \downarrow$$

Additional factors affecting final camber

- **Age of girder when deck placed**
- **Creep**
- **Differential shrinkage**
- **Environmental conditions**
- **Temperature**
- **Structural system**

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Multiplier Method for Estimating Camber

PS Element with Composite Deck (*PCI Handbook* 1994)

At Erection	
Deflection (downward) component - apply to the elastic deflection due to the member weight at release of prestress	**1.85**
Camber (upward) component - apply to the elastic camber due to prestress at the time of release of prestress	**1.80**
Final	
Deflection (downward) component - apply to the elastic deflection due to the member weight at release of prestress	**2.40**
Camber (upward) component - apply to the elastic camber due to prestress at the time of release of prestress	**2.20**
Deflection (downward) component - apply to elastic deflection due to superimposed dead load only	**3.00**
Deflection (downward) component - apply to the elastic deflection caused by the composite topping	**2.30**

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Multiplier Method for Estimating Camber

PS Element - no Composite Deck (*PCI Handbook* 1994)

At Erection			
Deflection (downward) component - apply to the elastic deflection due to the member weight at release of prestress	1.85	Same – no effect of composite properties	
Camber (upward) component - apply to the elastic camber due to prestress at the time of release of prestress	1.80		
Final		**Composite**	
Deflection (downward) component - apply to the elastic deflection due to the member weight at release of prestress	2.70	2.40	
Camber (upward) component - apply to the elastic camber due to prestress at the time of release of prestress	2.45	2.20	
Deflection (downward) component - apply to elastic deflection due to superimposed dead load only	3.00	3.00	
Deflection (downward) component - apply to the elastic deflection caused by the composite topping	---	2.30	

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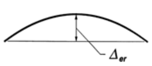
Computing Camber & Deflection

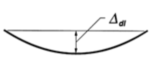
At Release

$\Delta_{rel} = \Delta_{ps}\uparrow + \Delta_{gdl}\downarrow$



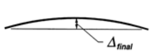
At Erection

$\Delta_{er} = 1.80\Delta_{ps}\uparrow + 1.85\Delta_{gdl}\downarrow$



Added Dead Loads

$\Delta_{dl} = \Delta_{ddl}\downarrow + \Delta_{ncdl}\downarrow + \Delta_{sdl}\downarrow$



Final

$\Delta_{final} = \Delta_{er}\uparrow + \Delta_{dl}\downarrow$

Multipliers for "Final" conditions are generally not used for composite girders.

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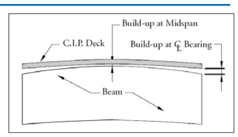
Determining Specified Build-Up at CL Bearings

Specifying correct build-up at CL of bearings is important to provide minimum build-up at critical location at midspan

- **Add minimum build-up requirement at midspan to estimated camber to define build-up at CL bearings**
- **Consider effect of cross-slope and camber (next slide)**



Contractor should determine top flange elevations of erected girders before setting screed elevations for deck

- **Bearing seat elevations can be adjusted to accommodate significant differences in camber between predictions and actual**

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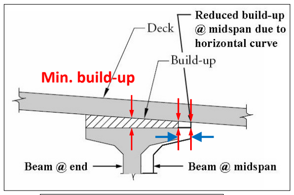
Horizontal Curve Effect on Required Build-up

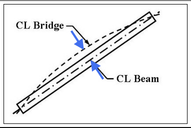
Build-up varies across top flange due to roadway cross-slope or super-elevation

With cross-slope, critical point for minimum build-up moves from CL of girder to edge of girder flange

With curvature, critical point for minimum build-up is shifted again because grade line is offset from CL of girder, further reducing the build-up

Defining required build-up at CL bearings that is used to set bearing seat elevations must account for all of these effects





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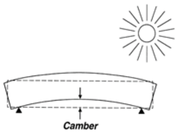
Other Camber Issues

Thermal camber
- Sun exposure increases camber
- Measure camber early in day



Bearing location during storage
- Moving support locations in from end reduces span and increases camber
- Moving supports in also improves stability

Differential camber between girders
- Complicates fit up for adjacent members
- Minimize effect with pre-assembly in plant for adjacent members

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Camber - Summary

Camber predictions are <u>estimates</u>

Even so-called “more exact methods” are only as good as accuracy of data and assumptions

Girder fabricators often have good understanding of their materials and processes so may have better estimate of expected cambers

Consider impact of camber variation
- Extra deck concrete, especially for wide-top girders
- Encroachment of girder into deck

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Camber - Summary

Detail structure to accommodate variation in camber
- Build-up is intended to provide some tolerance for variation in camber
- Provide minimum build-up in design to avoid top of girder moving into deck during construction

Methods to address cambers that differ from expected values in design
- Modify beam seats or bearing plates
- Revise roadway profile

The plant generally can do little to control or modify cambers

Some variation in camber between girders of the same design is normal

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