October 28-29, 2025
Orlando, FL

TRANSPORTATION SYMPOSIUM

Evolution of Camber Estimation in Florida's Prestressed Beams

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Transportation Symposium Website

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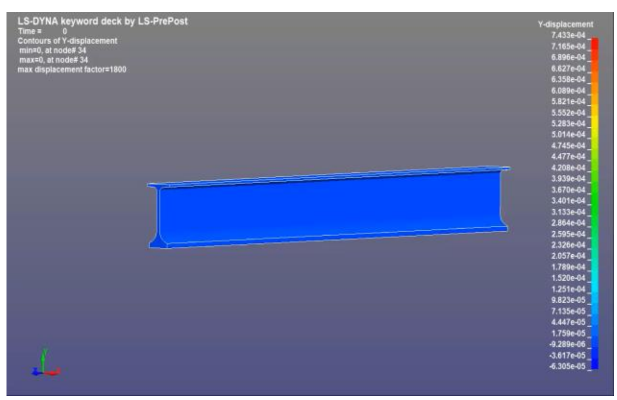
Fundamentals of Camber in Prestressed Beams

What is it?

The camber of a beam is the upwards deflections of the beam resulting from the eccentric prestressing force (either pretension or post-tension).

Why is it important?

Accurate camber estimates ensure the deck and build-up are placed as designed and ensure the bridge profile is met.



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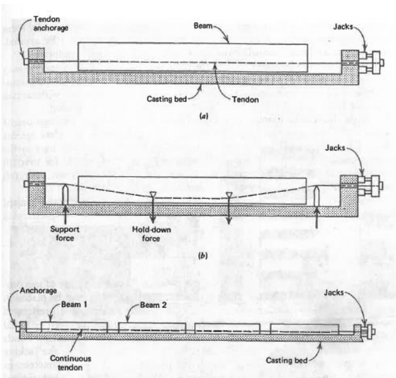

FIGURE 1.10 Methods of pretensioning. (*a*) Beam with straight tendon. (*b*) Beam with variable tendon eccentricity. (*c*) Long-line stressing and casting.

Nilson (1987)

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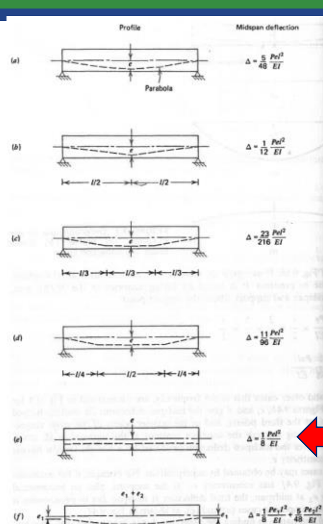

FIGURE 9.4 Prestress deflections for various tendon profiles.

Nilson (1987)

Straight strands are the preferred profile in FL standard Beams

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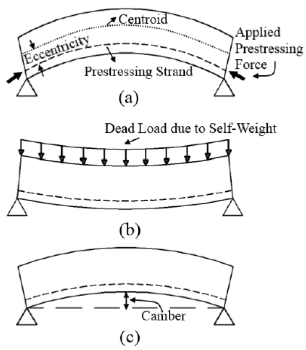
Fundamentals of Camber in Prestressed Beams

Camber could be calculated as follows:



Honavar (2015)

$$\Delta_{Camber} = \frac{P \cdot e \cdot L^2}{8 \cdot E \cdot I}$$

P = Prestressing force (after loss)
e = Eccentricity of prestress force
L = Span length
E = Modulus of elasticity
I = Moment of inertia

$$\delta_{SW} = \frac{5 \cdot w \cdot L^4}{384 \cdot E \cdot I}$$

w = Uniform load due to self-weight
L = Span length
E = Modulus of elasticity
I = Moment of inertia

$$\Delta_{net} = \Delta_{Camber} - \delta_{SW}$$

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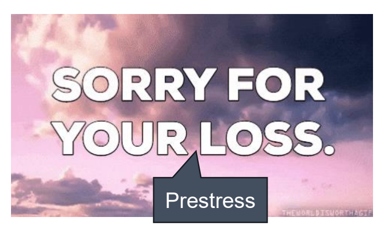
Fundamentals of Camber in Prestressed Beams

- Prestress Losses
  - Instantaneous or short-term
    - Elastic Shortening*
    - Anchorage Slip**
  - Time-Dependent or long-term
    - Approximate method
      - Δf_{pLT} Creep/Shrink./Relaxation
    - Refined method
      - Creep
      - Shrinkage
        - Beam
        - Deck
      - Strand Relaxation



*Unless using transformed section properties
**Typically only considered for post-tension

SDG 4.3.1.C.7

7. Stress and camber calculations for the design of simple span, pretensioned components must be based upon the use of transformed section properties.

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Fundamentals of Camber in Prestressed Beams

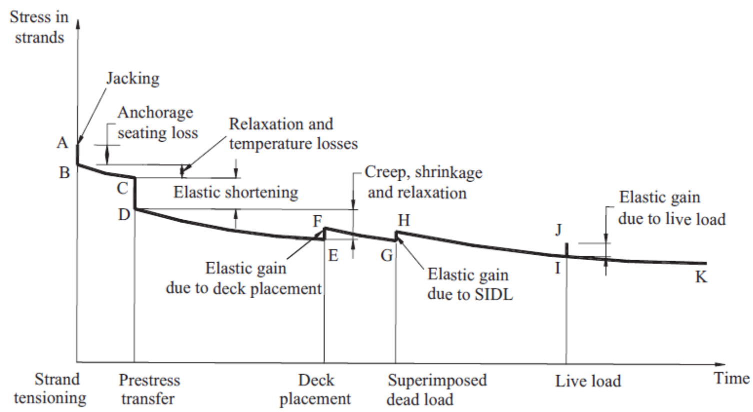

Figure 1. Stress versus time in the strands in a pretensioned concrete girder.

(NCHRP Report 496)

Fundamentals of Camber in Prestressed Beams

LRFD 5.9.3.4 – Refined Prestress Losses (pretension members)

$$\Delta f_{pT} = \Delta f_{pES} + \Delta f_{pLT}$$ LRFD 5.9.3.1-1

Elastic Shortening | Time-Dependent

Time step from Release to Deck Placement

Time step from Deck Placement to final

$$\Delta f_{pLT} = (\Delta f_{pSR} + \Delta f_{pCR} + \Delta f_{pR1})_{id} + (\Delta f_{pSD} + \Delta f_{pCD} + \Delta f_{pR2} - \Delta f_{pSS})_{df}$$ LRFD 5.9.3.4.1-1

Shrinkage | Creep | Relax. | Shrinkage | Creep | Relax. | Shrinkage (deck)

Shrinkage: Loss of prestress associated with the drying shrinkage of concrete, the reduction of strain in the prestressing steel is equal to the shrinkage strain of concrete.

Creep: Loss of prestress resulting from the gradual, time-dependent deformation of concrete under sustained stress.

Strand Relaxation: Loss of prestress in strands under sustained load while held at constant length.

Fundamentals of Camber in Prestressed Beams

LRFD 5.9.3.3 – Approximate Method of time dependent losses

$$\Delta f_{pLT} = \frac{10 \cdot f_{pi} \cdot A_{ps}}{A_g} \gamma_h \cdot \gamma_{st} + 12 \cdot \gamma_h \cdot \gamma_{st} + \Delta f_{pR}$$

$$\gamma_h = 1.7 - 0.01 \cdot H$$

$$\gamma_{st} = \frac{5}{(1 + f`_{ci})}$$

f_{pi} = prestressing steel stress immediately prior to transfer (ksi)

γ_h = correction factor for relative humidity of the ambient air

γ_{st} = correction factor for specified concrete strength at time of prestress transfer to the concrete member

Δf_{pR} = an estimate of relaxation loss taken as 2.4 ksi for low relaxation strand and in accordance with manufacturers recommendation for other types of strand (ksi)

H = average annual ambient relative humidity (percent)

SDG 4.3.1.C.6

6. When calculating the Service Limit State capacity for pretensioned concrete flat slabs and girders, use the transformed section properties as follows: at strand transfer; for calculation of prestress losses; for live load application. For precast, pretensioned, normal weight concrete members designed as simply supported beams, use ***LRFD*** 5.9.3.3, Approximate Estimate of Time-Dependent Losses. For all other members use ***LRFD*** 5.9.3.4 with a 180-day differential between girder concrete casting and placement of the deck concrete.

Commentary: The FDOT cannot practically control, nor require the Contractor to control, the construction sequence and materials for simple span precast, prestressed beams. To benefit from the use of refined time-dependent analysis, literally every prestressed beam design would have to be re-analyzed using the proper construction times, temperature, humidity, material properties, etc. of both the beam and the yet-to-be-cast composite slab.

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Fundamentals of Camber in Prestressed Beams

Prestress Losses Comparison

Beam	Spacing (ft)	Span (ft)	D/C for Moment	D/C for Ser III w/ Simplified	
				PS+DL+0.8LL	PS+DL+1.0
FSB12x53	-	40	0.81	**0.95**	1.03
FSB15x53	-	50	0.85	**0.97**	1.05
FSB18x53	-	60	0.89	**0.97**	1.06
Type II	7	60	0.85	**0.89**	0.99
FIB36	8	97	0.84	**0.96**	1.06
FIB45	8	117	0.83	**0.95**	1.04
FIB54	8	132	0.87	**0.98**	1.07
FIB63	8	145	0.86	**0.97**	1.05
FIB72	8	163	0.85	**0.97**	1.04
FIB78	8	172	0.85	**0.97**	1.03
FIB84	8	181	0.83	**0.95**	1.02
FIB96	8	198	0.84	**0.97**	1.03
FIB96	12	178	0.81	**0.95**	1.02

Beam	Difference
FSB12x53	-1%
FSB15x53	-5%
FSB18x53	-4%
Type II	-8%
FIB36	6%
FIB45	10%
FIB54	11%
FIB63	11%
FIB72	14%
FIB78	15%
FIB84	15%
FIB96	17%
FIB96	9%

me
p df

Refined totals

Approx. totals

...ating Time-Dependent Losses (ksi)					Simplified	Difference
...pCD	Δf.pR2	Δf.pSS	Δf.pSS WAI 227	Total	Total	
.24	1.56	0.08	0.02	21.48	21.16	-1%
.23	1.55	-0.05	-0.01	22.17	20.99	-5%
.16	1.53	-0.02	-0.01	22.47	21.63	-4%
.54	1.43	-0.96	-0.28	23.66	21.86	-8%
.04	1.34	-0.98	-0.28	24.13	25.68	6%
.00	1.31	-0.89	-0.26	24.57	26.99	10%
.75	1.36	-0.91	-0.26	23.33	25.88	11%
.69	1.38	-0.91	-0.26	22.92	25.51	11%
.63	1.36	-0.88	-0.26	23.09	26.30	14%
.59	1.37	-0.89	-0.26	22.91	26.25	15%
.60	1.36	-0.88	-0.26	22.99	26.45	15%
.48	1.38	-0.90	-0.26	22.37	26.09	17%
.74	1.30	-0.99	-0.29	24.42	26.58	9%

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Fundamentals of Camber in Prestressed Beams

Table 8.7.1-1
Suggested Multipliers to be Used as a Guide in
Estimating Long-Term Cambers and Deflections for Typical Members

		Without Composite Topping	With Composite Topping
	At erection:		
(1)	Deflection (↓) component—apply to the elastic deflection due to the member weight at transfer of prestress	1.85	1.85
(2)	Camber (↑) component—apply to the elastic camber due to prestress at the time of transfer of prestress	1.80	1.80
	Final:		
(3)	Deflection (↓) component—apply to the elastic deflection due to the member weight at transfer of prestress	2.70	2.40
(4)	Camber (↑) component—apply to the elastic camber due to prestress at the time of transfer of prestress	2.45	2.20
(5)	Deflection (↓) component—apply to elastic deflection due to superimposed dead load only	3.00	3.00
(6)	Deflection (↓) component—apply to elastic deflection caused by the composite topping	—	2.30

PCI (2023)

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Fundamentals of Camber in Prestressed Beams

FDOT State Structures Design Office

FDOT LRFD Prestressed Beam Program v6.2

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Subscript "t" is a time step e.g. from 0 days to 30 days

$$\Delta_t = \Delta_{pe} + \frac{\Delta_{pi} + \Delta_{pe}}{2} C_t - \Delta_{sw}(1 + C_t)$$

Losses based on Approx. method

Creep Coefficient applied to both camber and self-weight deflections

Field Verification of Camber Estimates for Prestressed Concrete Bridge Girders (Cook 2005)

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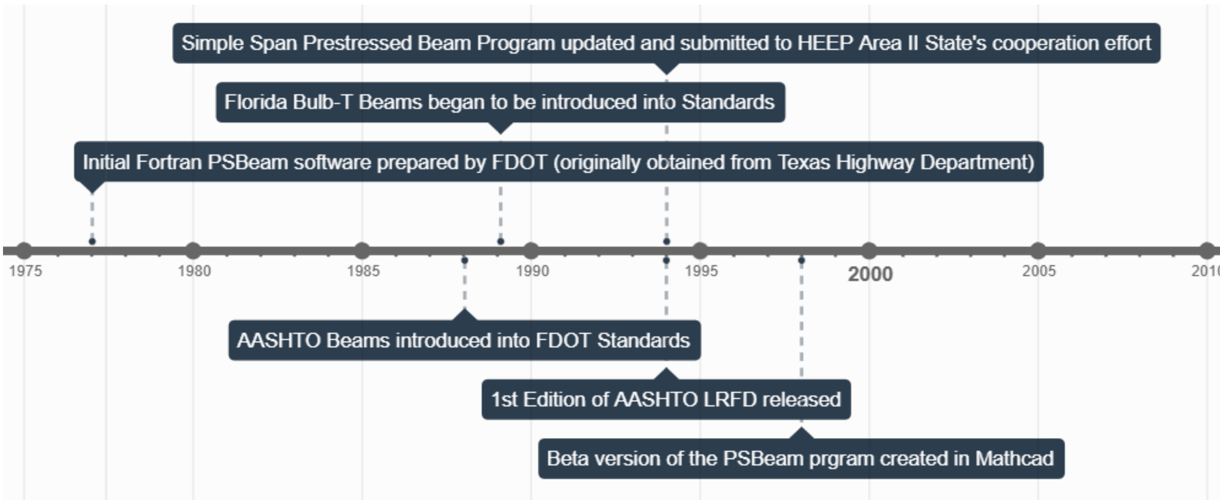
History of Camber Estimation in Florida



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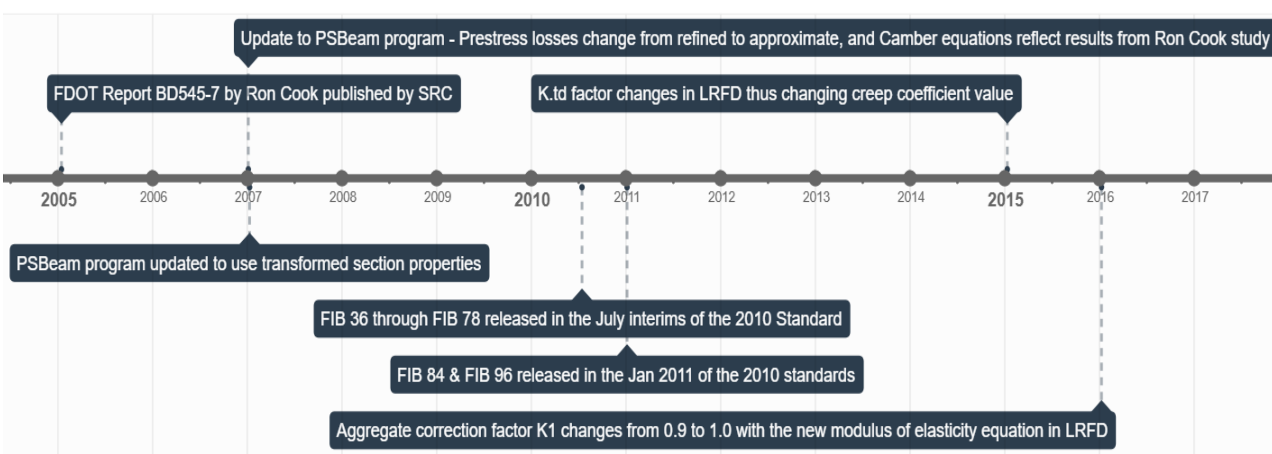
History of Camber Estimation in Florida



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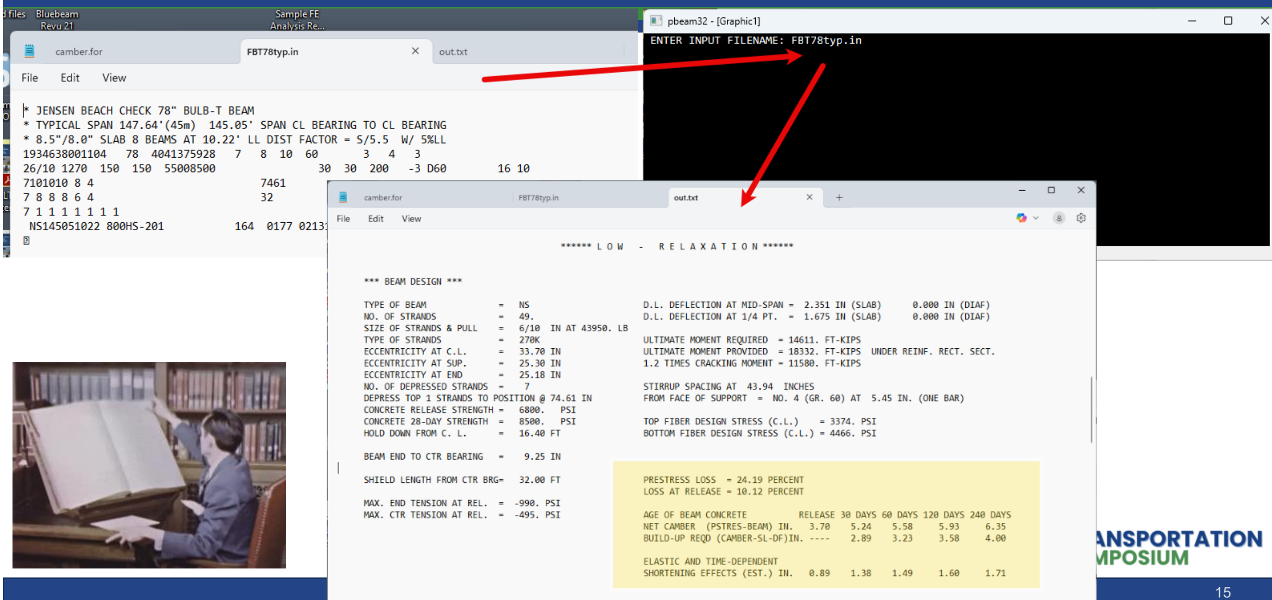

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History of Camber Estimation in Florida

THE DESIGN AND ANALYSIS OF SIMPLE SPAN PRESTRESSED CONCRETE BEAMS COMPUTER PROGRAM USER'S MANUAL

Version 2.50

Depressed Strand Design and Analysis

Prepared By
A. J. Haywood, P.E.
W. L. Woolery, P.E.

Straight Strand Design and Analysis

Prepared By
R. E. Nichols, P.E.
L. Y. Hsia, P.E.

UPDATED BY
R. E. Nichols, P.E.
L. Y. Hsia, P.E.

Structures Design Office
Florida Department of Transportation

May 1994

By definition, the net camber at beam ages of release 30 days, 60 days, 120 days and 240 days is reported as:

$$C_{max_t} = C_{1_t}(\Delta P - \Delta S) - C_{2_t}(\Delta B)$$

Prestress Force
Factor to account for debonded/draped strands
Dead load deflection

C_1 and C_2 are values at time "t" to account for the "aging" modulus of the beam concrete and the creep effect of Florida concrete materials as related to time. By definition, the values are:

Table 1-2 Camber Constants C_1, C_2

BEAM AGE IN DAYS	C_1	C_2
Release	1.35	1.22
30	2.09	2.07
60	2.26	2.27
120	2.43	2.47
240	2.60	2.64

Manual for The Design and Analysis of Simple Span Prestressed Concrete Beams Computer Program V2.5 (FDOT 1994)

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History of Camber Estimation in Florida

Table 5.9.5.3-1 - Time-Dependent Losses in MPa

Type of Beam Section	Level	For Wires and Strands with f_{pu} = 1620, 1725 or 1680 MPa	For Bars with f_{pu} = 1000 or 1100 MPa
Rectangular Beams and Solid Slabs	Upper Bound Average	200 + 28 PPR 180 + 28 PPR	130 + 41 PPR
Box Girder	Upper Bound Average	145 + 28 PPR 130 + 28 PPR	100
I-Girder	Average	$230\left[1-0.15\frac{f'_c-41}{41}\right]+41\,PPR$	130 + 41 PPR
Single T, Double T, Hollow Core and Voided Slab	Upper Bound Average	$270\left[1.0-0.15\frac{f'_c-41}{41}\right]+41\,PPR$ $230\left[1.0-0.15\frac{f'_c-41}{41}\right]+41\,PPR$	$210\left[1.0-0.15\frac{f'_c-41}{41}\right]+41\,PPR$

Approximate

5.9.5.4.2 Shrinkage

Loss of prestress due to shrinkage may be taken as:

- for pretensioned members:

$$\Delta f_{pSR} = (117 - 1.03\,H)\ \text{(MPa)} \qquad (5.9.5.4.2\text{-}1)$$

- for post-tensioned members:

$$\Delta f_{pSR} = (93 - 0.85\,H)\ \text{(MPa)} \qquad (5.9.5.4.2\text{-}2)$$

where:

H = the average annual ambient relative humidity (%)

5.9.5.4.3 Creep

Prestress loss due to creep may be taken as:

$$\Delta f_{pCR} = 12.0\,f_{cgp} - 7.0\Delta f_{cdp} \geq 0 \qquad (5.9.5.4.3\text{-}1)$$

where:

f_{cgp} = concrete stress at center of gravity of prestressing steel at transfer (MPa)

Δf_{cdp} = change in concrete stress at center of gravity of prestressing steel due to permanent loads, except the load acting at the time the prestressing force is applied. Values of Δf_{cdp} should be calculated at the same section or sections for which f_{cgp} is calculated (MPa).

5.9.5.4.4 Relaxation

5.9.5.4.4a General

The total relaxation at any time after transfer shall be taken as the sum of the losses specified in Articles 5.9.5.4.4b and 5.9.5.4.4c.

5.9.5.4.4b At Transfer

In pretensioned members, the relaxation loss in prestressing steel, initially stressed in excess of 0.50 f_{pu}, may be taken as:

- for stress-relieved strand:

$$\Delta f_{pR1} = \frac{\log(24.0t)}{10.0}\left[\frac{f_{pj}}{f_{py}} - 0.55\right]f_{pj} \qquad (5.9.5.4.4\text{b-}1)$$

- for low-relaxation strand:

$$\Delta f_{pR1} = \frac{\log(24.0t)}{40.0}\left[\frac{f_{pj}}{f_{py}} - 0.55\right]f_{pj} \qquad (5.9.5.4.4\text{b-}2)$$

where:

t = time estimated in days from stressing to transfer (DAYS)

f_{pj} = initial stress in the tendon at the end of stressing (MPa)

f_{py} = specified yield strength of prestressing steel (MPa)

1st Ed. AASHTO LRFD (1994)

Refined

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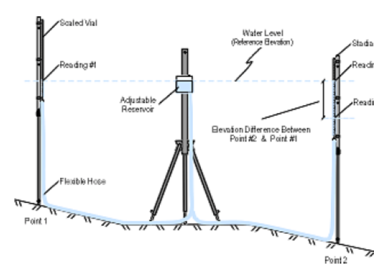
Fundamentals of Camber in Prestressed Beams

How and when is it measured?

Optical targets with theodolite

(Cook 2005)



Water manometer level

(Cook 2005)

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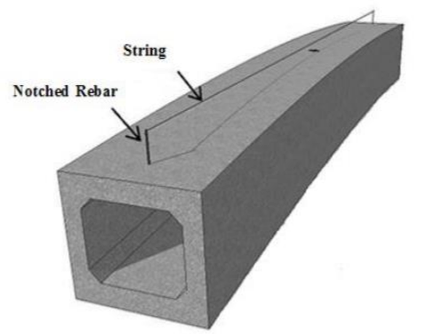

String line approach
(Rizkalla 2011)

8.3.2.1 Camber Measurement Procedure

The currently adopted camber measurement method is not consistent. The measurement technique and the location on the PPCBs from which the measurements are taken vary. By observing and taking independent camber measurements, this study concluded that the error in camber arising from the measurement technique used by the precasters and contractors was about 26%, on average. To eliminate the difference in camber values due to the measurement technique, the researchers developed a simplified procedure that both precasters and contractors can use to accurately measure the camber and minimize any error associated with the measurement technique. The following are recommendations for the new camber measurement procedure:

(Honavar 2015)   230

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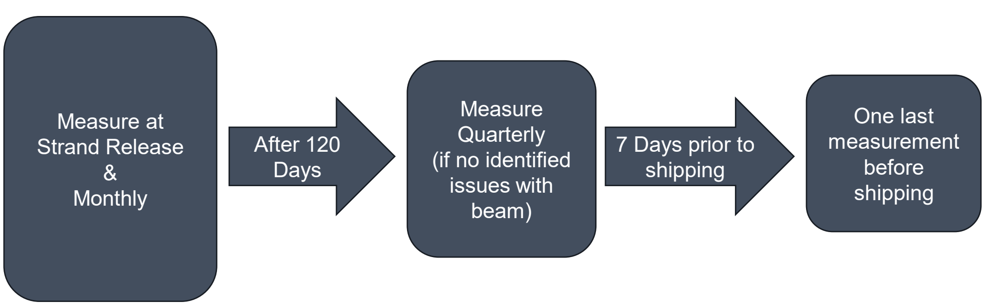
Fundamentals of Camber in Prestressed Beams

Frequency of Camber Measurements (per FDOT Spec 450)



"Keep the measurement records on file for review upon request by the Engineer"

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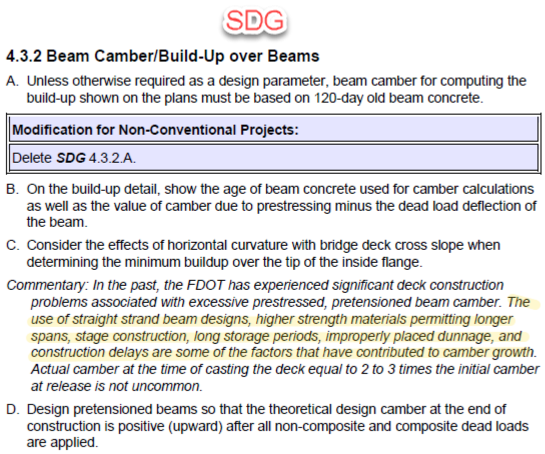

SDG

4.3.2 Beam Camber/Build-Up over Beams

A. Unless otherwise required as a design parameter, beam camber for computing the build-up shown on the plans must be based on 120-day old beam concrete.

Modification for Non-Conventional Projects:
Delete ***SDG*** 4.3.2.A.

B. On the build-up detail, show the age of beam concrete used for camber calculations as well as the value of camber due to prestressing minus the dead load deflection of the beam.

C. Consider the effects of horizontal curvature with bridge deck cross slope when determining the minimum buildup over the tip of the inside flange.

Commentary: In the past, the FDOT has experienced significant deck construction problems associated with excessive prestressed, pretensioned beam camber. The use of straight strand beam designs, higher strength materials permitting longer spans, stage construction, long storage periods, improperly placed dunnage, and construction delays are some of the factors that have contributed to camber growth. Actual camber at the time of casting the deck equal to 2 to 3 times the initial camber at release is not uncommon.

D. Design pretensioned beams so that the theoretical design camber at the end of construction is positive (upward) after all non-composite and composite dead loads are applied.

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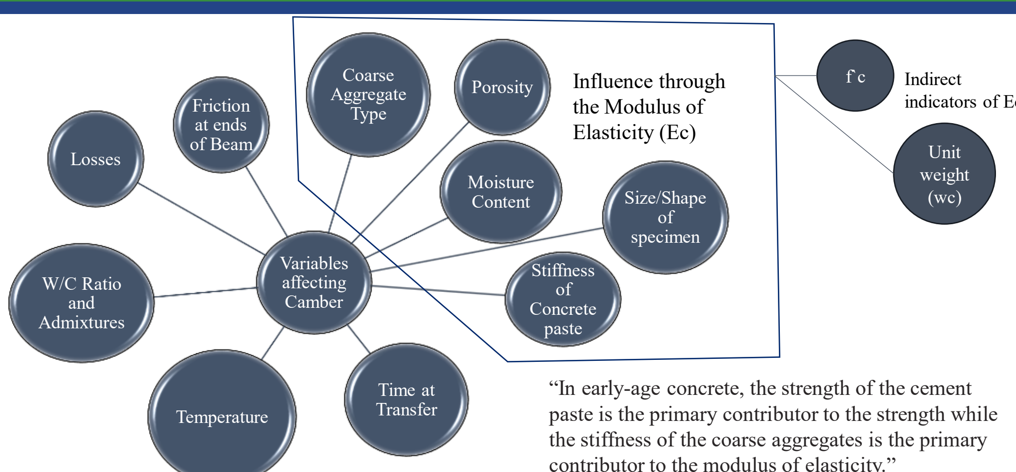
Inevitable Camber Variations



"In early-age concrete, the strength of the cement paste is the primary contributor to the strength while the stiffness of the coarse aggregates is the primary contributor to the modulus of elasticity."
NCHRP RPT 496 (2003)

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Inevitable Camber Variations

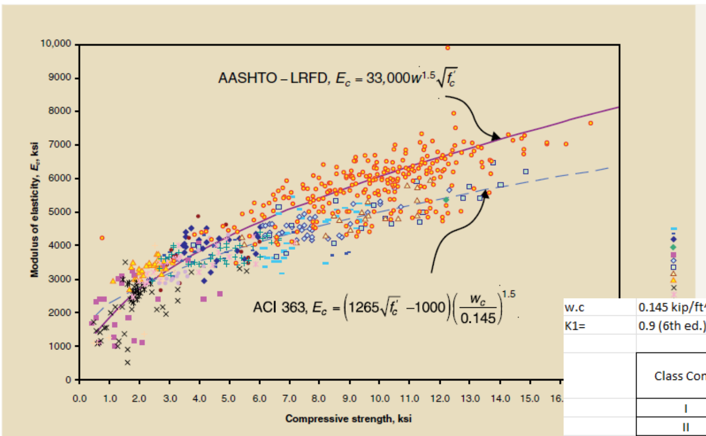

Figure 7. This chart shows the modulus of elasticity versus compressive strength as reported by Tadros et al. (2003).[1] Note: E_c = modulus o tion, assumed to be the same as modulus at service (or final time); f'_c = specified concrete strength at final service conditions; w = density (density) of concrete. 1 ksi = 6.894 MPa.

Tadros (2011)

w.c	0.145 kip/ft^3			
K1=	0.9 (6th ed.) / 1.0 (7th ed.)			

		LRFD Equation for Modulus of Elasticity (Ec)		
		6th Ed. and previous	7th Ed. and after	
Class Conc.	f`c (ksi)	$33{,}000K_1w_c^{1.5}\sqrt{fc`}$	$120{,}000K_1w_c^2fc`^{0.33}$	% Increase
I	3	2840	3625	27.64
II	3.4	3024	3778	24.96
II (Bridge Deck)	4.5	3479	4145	19.14
III	5	3667	4291	17.03
IV	5.5	3846	4428	15.15
IV (Drilled Shaft)	4	3280	3987	21.55
V	6.5	4181	4679	11.92
VI	8.5	4781	5112	6.93
VII	10	5186	5394	4.02

Inevitable Camber Variations

FDOT Standard Specifications

346-9.7 Structural Adequacy: The Engineer will evaluate the structural adequacy for verified concrete that does not meet the minimum specified compressive strength of Table 346-3.

For structural adequacy, with standard molded and cured compressive strength cylinders, the compressive strength of concrete is satisfactory provided that the two following criteria are met:

1. The average compressive strength does not fall below the specified minimum compressive strength by more than:
   a. 500 psi if the specified minimum compressive strength is equal to or less than 5,000 psi.
   b. 10% of the specified minimum compressive strength if the specified minimum compressive strength is greater than 5,000 psi.
2. The average compressive strength with the previous two LOTs is equal to or exceeds the specified minimum compressive strength. This condition only applies if there are two or more previous LOTs to calculate the average.

The Engineer will consider the concrete for a given LOT as structurally adequate and coring will not be allowed when a concrete compressive strength test result falls below the specified minimum strength but has met the above conditions.

Class VI (f’c = 8,500)

$$8{,}500 - 0.10 \cdot 8{,}500 = 7{,}650\ psi$$

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Inevitable Camber Variations

FDOT Materials Manual

9.2.7 MIX DESIGNS

9.2.7.1 General

Concrete mix designs shall meet the requirements of ***Specification Section 346***. Plants may follow ACI 301 Section 4, and ACI 211 as guidelines to design concrete mixes.

When the Engineer determines that unsatisfactory results are obtained during production, the mix design approval will be rescinded.

Design a concrete mix to provide a required compressive strength (***f'cr***) that exceeds the specified minimum compressive strength (***f'c***) by the overdesign value.

$$f'cr = f'c + Overdesign$$

Proceed as follows to select the overdesign value in concrete mixes:

(1) For a class of concrete, submit compressive strength field test data for the past 24 months and spanning no less than 45 calendar days, to determine the standard deviation. The ***f'c*** is required to be within 1,000 psi. The strength test data represents either a group of at least 30 consecutive tests or a statistical average for two groups totaling 30 or more tests. Determine the overdesign as follow:

a. When ***f'c*** is equal to or less than 5,000 psi.

$$Overdesign = 2.33\ x\ Standard\ Deviation - 500\ psi$$

b. When ***f'c*** is greater than 5,000 psi.

$$Overdesign = 2.33\ x\ Standard\ Deviation - 0.10xf'c$$

(2) Use Table 1 at the concrete producer's option, or when the concrete producer has no records of field strength tests performed within the past 24 months and spanning no less than 45 calendar days for a class of concrete within 1,000 psi of that ***f'c***.

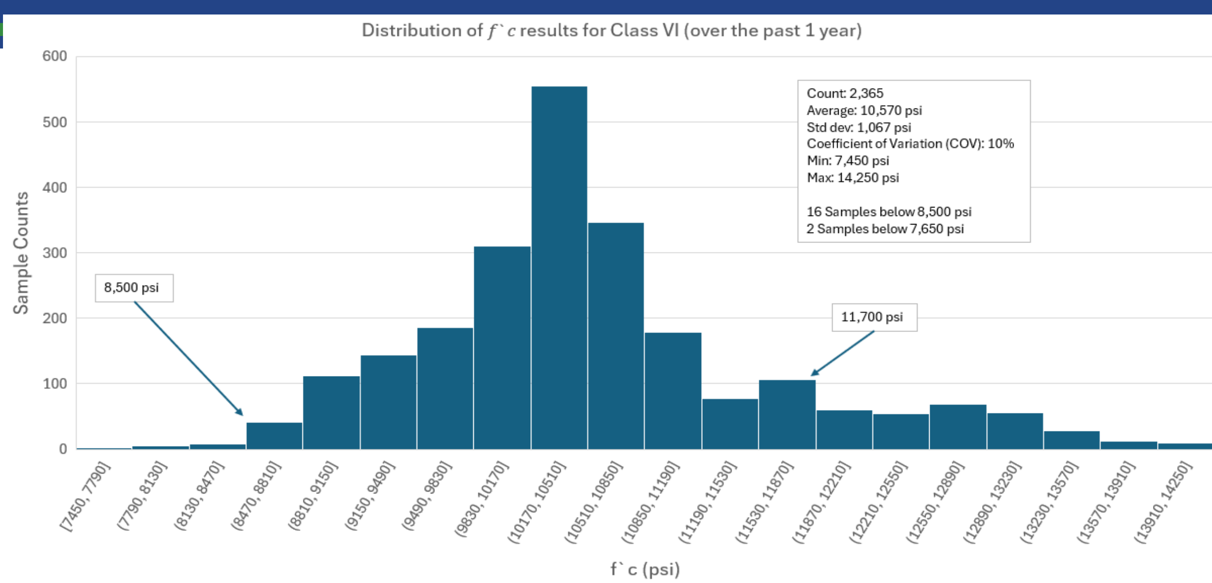
FDOT Materials Manual

TABLE 1 – Overdesign requirements for establishing ***f'cr*** when data is not available at 28-day or 56-day whichever is applicable

Class of Concrete	***f'c*** (psi)	Overdesign (psi)	***f'cr*** (psi)	Maximum Allowable Compressive Strength (psi)
I Seal	3,000	1,200	4,200	5,200
I Pavement	3,000	Not Specified	Not Specified	5,200
II	3,400	1,200	4,600	5,700
II Bridge Deck	4,500	1,200	5,700	6,750
III	5,000	1,200	6,200	6,750
IV	5,500	1,250	6,750	7,850
IV Drilled Shaft	4,000	1,200	5,200	6,200
V	6,500	1,350	7,850	10,050
VI	8,500	1,550	10,050	11,700
VII	10,000	1,700	11,700	13,000

TRANSPORTATION SYMPOSIUM

Inevitable Camber Variations



Inevitable Camber Variations

Example f`c vs Δ_{Camber} Calculation (ignoring losses)

$$\Delta_{Camber} = \frac{P \cdot e \cdot L^2}{8 \cdot E \cdot I}$$

P = Prestressing force (after loss)
e = Eccentricity of prestress force
L = Span length
E = Modulus of elasticity
I = Moment of inertia

$$\delta_{SW} = \frac{5 \cdot w \cdot L^4}{384 \cdot E \cdot I}$$

w = Uniform load due to self-weight
L = Span length
E = Modulus of elasticity
I = Moment of inertia

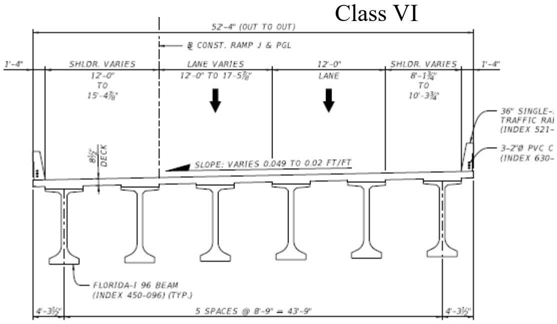
$$\Delta_{net} = \Delta_{Camber} - \delta_{SW}$$

	f`c (ksi)	E (ksi)	Δ_{Camber} (in.)	δ_{SW} (in.)	Δ_{net} (in.)
f`c↓ Δ_{Camber}↑	8.5	5,112	3.10	2.03	1.07
f`c↑ Δ_{Camber}↓	12.70	5,837	2.72	1.78	0.94
Diff.	4.2	725	0.38	0.25	0.13

TRANSPORTATION SYMPOSIUM

Inevitable Camber Variations

L = 200ft
Class VI

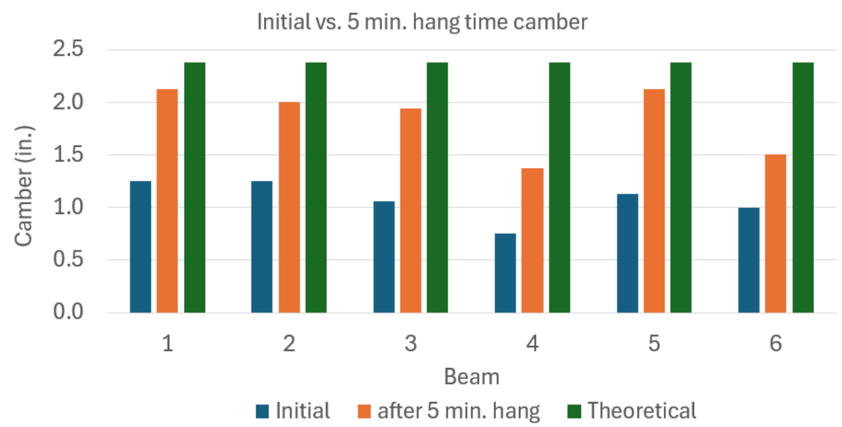


SECTION THROUGH BRIDGE

BUILD-UP & DEFLECTION DATA TABLE FOR PRESTRESSED I-BEAMS									TABLE DATE 7-01-17
LOCATION		REQUIRED THEORETICAL BUILD-UP OVER ℄ BEAM			NET BEAM CAMBER (PRESTRESS - DEAD LOAD OF BEAM) @ RELEASE	NET BEAM CAMBER (PRESTRESS - DEAD LOAD OF BEAM) @ 120 DAYS	DEAD LOAD DEFLECTION DURING DECK POUR @ 120 DAYS DIM A	BUILD-UP CASE NO.	
SPAN NO.	BEAM NO.	AT BEGIN SPAN DIM B	AT ℄ SPAN DIM C	AT END SPAN DIM D					
1	1	1¾"	3"	1⅛"	2⅜"	5½"	3⅝"	4	
1	2	1¾"	4⅝"	1"	2⅜"	5½"	4⅜"	4	
1	3	1¾"	5¼"	1"	2⅜"	5½"	4⅜"	4	
1	4	1¾"	5¼"	1"	2⅜"	5½"	4⅜"	4	
1	5	1¾"	4¾"	1"	2⅜"	5½"	4⅜"	4	
1	6	1¾"	2⅞"	1"	2⅜"	5½"	3⅝"	4	

TRANSPORTATION SYMPOSIUM

Inevitable Camber Variations



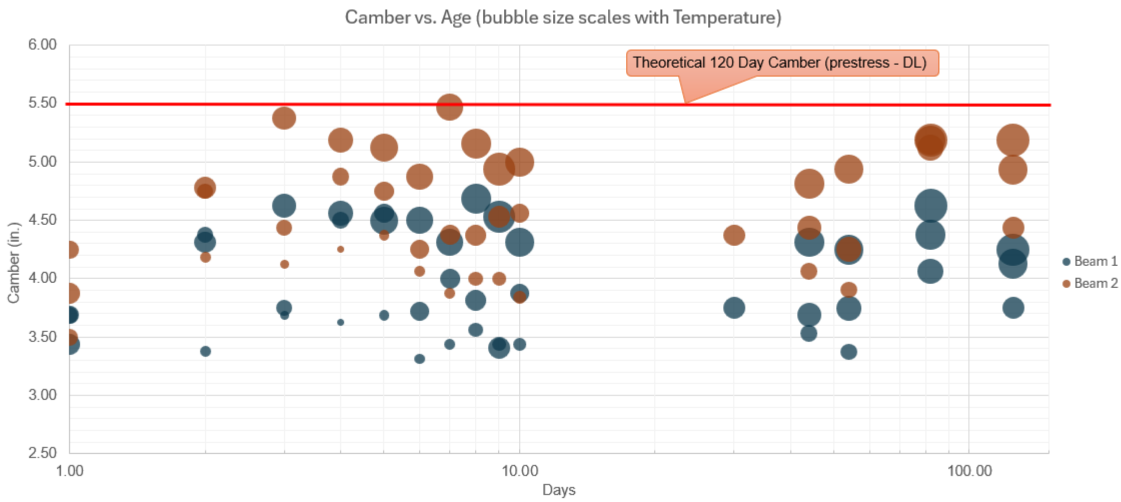
TRANSPORTATION SYMPOSIUM

Inevitable Camber Variations

CAMBER	Ambient Temp at time of Check	Beam Temp at time of Check	DATE	CAMBER	Ambient Temp at time of Check	Beam Temp at time of Check	DATE	CAMBER	Ambient Temp at time of Check	Beam Temp at time of Check	DATE	CAMBER	Ambient Temp at time of Check	Beam Temp at time of Check	DATE	Max dif. in Camber measurements (in.)
4.313	86°F	95.6°F	4-17-24 3:30PM	3.563	67°F	77.6°F	4-18-24 5:30AM	3.813	77°F	76.2°F	4/18/2024 10:30AM	4.688	89°F	95.7°F	4-18-24 3:30PM	1.125
5.469	86°F	90.6°F	4-17-24 3:30PM	4.000	67°F	77.9°F	4-18-24 5:30AM	4.375	77°F	75.6°F	4/18/2024 10:30AM	5.156	89°F	90.6°F	4-18-24 3:30PM	1.156
4.875	86°F	80.9°F	4-24-24 3:30PM	3.938	61°F	73.5°F	4-25-24 5:30AM	4.375	77°F	73.2°F	4-25-24 11:00AM	4.906	84°F	83.9°F	4-25-24 3:00PM	0.968
3.875	86°F	75.2°F	4-24-24 3:30PM	3.063	61°F	74.7°F	4-25-24 5:30AM	3.594	77°F	71.1°F	4-25-24 11:00AM	3.906	84°F	78°F	4-25-24 3:00PM	0.843
3.250	72°F	79°F	5-3-24 5:30AM	3.688	82°F	87.1°F	5-3-24 11:02AM	3.875	82°F	98.1°F	5-3-24 12:30PM	3.250	65°F	77.6°F	5-4-24 5:30AM	0.625
3.188	72°F	80.3°F	5-3-24 5:30AM	3.750	82°F	81.8°F	5-3-24 11:02AM	3.813	82°F	87.6°F	5-3-24 12:30PM	3.125	65°F	80.4°F	5-4-24 5:30AM	0.625

TRANSPORTATION SYMPOSIUM

Inevitable Camber Variations



ATION
SYMPOSIUM

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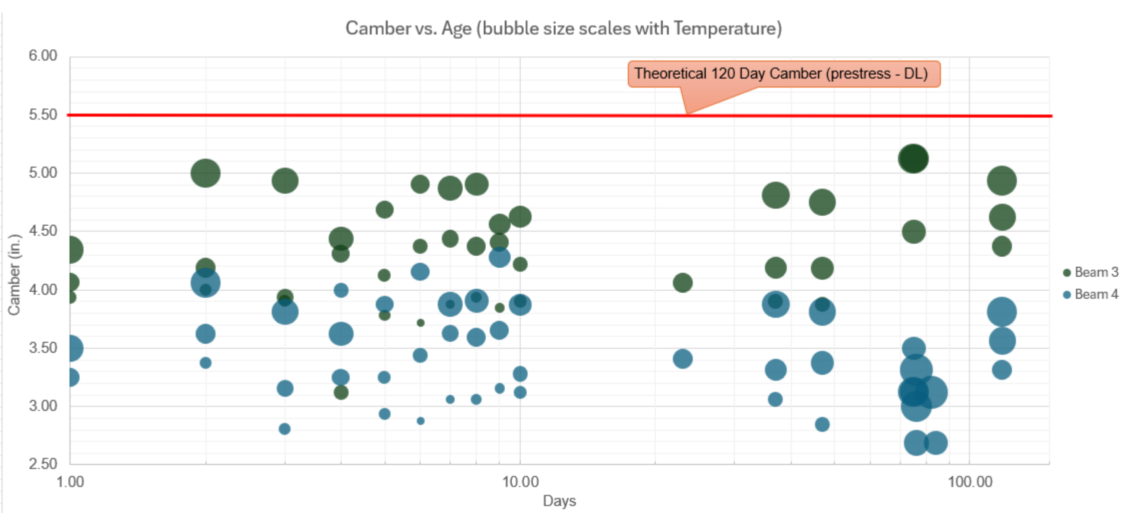
Inevitable Camber Variations



ATION

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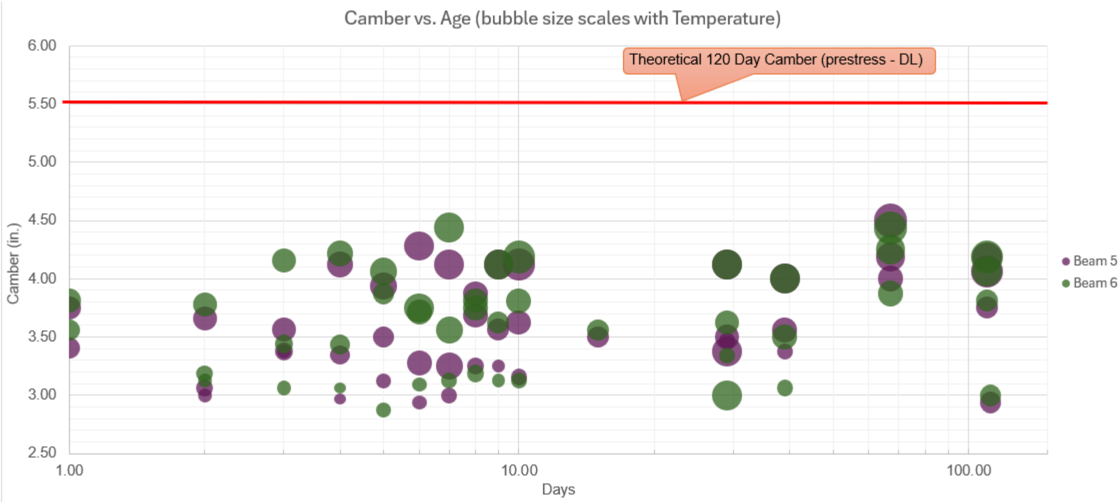
Inevitable Camber Variations



TATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done Today

450-072		Florida-I 72 Beam - Standard Details	20072		
450-078		Florida-I 78 Beam - Standard Details	20078		
450-084		Florida-I 84 Beam - Standard Details	20084		
450-096		Florida-I 96 Beam - Standard Details	20096		
450-120		AASHTO Type II Beam	20120	SPI	PGM
450-199		Prestressed I-Beams Build-Up and Deflection Data	20199	SPI	
450-210		Florida-U Beam - Typical Details and Notes	20210		
450-248		Florida-U 48 Beam - Standard Details	20248		

BEAM CAMBER AND BUILD-UP NOTES:

The build-up values given in the Data Table are based on theoretical beam cambers. The Contractor shall monitor beam cambers for the purpose of predicting camber values at the time of the deck pour. If the predicted cambers based on field measurements differ more than +/- 1" from the theoretical "Net Beam Camber @ 120 Days" shown in the Data Table*, obtain approval from the Engineer to modify the build-up dimensions as required. When the measured beam cambers create a conflict with the bottom mat of deck steel, notify the Engineer a minimum of 21 days prior to casting.*

<u>Standard Spec 450-2.3</u>
"If the camber is outside the design camber shown in the plans by plus or minus 1 inch, take appropriate actions to accommodate the product in the structure."

Plan Content Requirements

Complete the following "Build-Up and Deflection Data Table for AASHTO Type II and Florida-I Beams" and include it on the superstructure detail sheets. See *FDM* **115** for more information regarding use of Data Tables.

BUILD-UP & DEFLECTION DATA TABLE FOR PRESTRESSED I-BEAMS (Table Date 07/01/17)

LOCATION		REQUIRED THEORETICAL BUILD-UP OVER ℄ BEAM			NET BEAM CAMBER (PRESTRESS - DEAD LOAD OF BEAM) @ RELEASE	NET BEAM CAMBER (PRESTRESS - DEAD LOAD OF BEAM) @ 120 DAYS	DEAD LOAD DEFLECTION DURING DECK POUR @ 120 DAYS DIM A	BUILD-UP CASE NO.
SPAN NO.	BEAM NO.	AT BEGIN SPAN DIM B	AT ℄ SPAN DIM C	AT END SPAN DIM D				

NOTES: Work this sheet with Standard Plans Index 450-199.

TRANSPORTATION SYMPOSIUM

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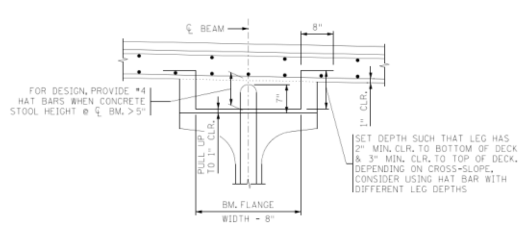
Managing & Mitigating: What Can Be Done Today

- Camber too Low
  - Per spec 450, if camber is less than 50% of predicted camber at release. Adjust dunnage inwards to induce camber. (Ask the precaster when did they measure the release camber, did they pick it up and set it back down? did they move it to storage before measuring?)
  - (For Negative Camber Beams) Does the beam still meet stress limits? Will it still load rate? does it meet vertical clearance?
  - Have the beam seats been cast already? Can they be raised?
  - Can we adjust the roadway profile?

TRANSPORTATION SYMPOSIUM

Managing & Mitigating: What Can Be Done Today

- Camber too High
  - Have the beam seats been cast already? Can they be lowered?
  - Is the beam interfering with the bottom mat of deck reinforcing?
  - Build-up at the end spans maybe too large for beam shear stirrups to embed in deck, consider 'hat' bars to bridge the gap.



HAT BAR FOR BEAMS WITH LARGE STOOL HEIGHTS

MNDOT

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Managing & Mitigating: What Can Be Done Today

- The time of day which the precaster could take camber measurements to eliminate effect of temperature/solar radiation.
- Ask for the Cylinder breaks for your beams, Remember f`c↑ Δ_{Camber}↓
- Ask the precaster for camber data on previous beams they've cast.

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done Today

Reach out to your district structural materials engineer.

Staff Directory

District Materials Office Contacts

D1-7 Materials | D2 Materials | D3 Materials | D4-6 Materials | D5 Materials | Turnpike Materials

District Materials Engineers (DMREs)

Additional Information

Florida Center for Pavement Excellence Contacts

MAC Primary Contacts (DACs, Development, etc.)

Research Management Team

https://www.fdot.gov/materials/administration/resources/contacts/staffdirectory.shtm
(https://tinyurl.com/muweb9em)

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done Today

FDOT Standard Specs 450-14.2

Support prestressed products that are stacked by dunnage placed across the full width of each bearing point and aligned vertically over lower supports. Move dunnage points in accordance with 450-2.3 with the approval of the QC Manager. Do not use stored products as a storage area for either shorter or longer products or heavy equipment.

Where feasible, base the selection of storage sites, storage conditions and orientation upon consideration of minimizing the thermal and time-dependent creep and shrinkage effects on the camber and/or sweep of the precast pretensioned products.

Continuous application of water during the initial 72 hour moist curing period may be interrupted for a maximum of one hour to allow relocation of precast prestressed concrete elements within the manufacturing facility. Keep the moist burlap in place during relocation of the element.

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Managing & Mitigating: What Can Be Done, Moving Forward

- What research can accomplish

Home / Structures / Structures Research Center

SRC Home | Active Research | Completed Research | Contact Us

10/15/2020	Diagnostic Investigation of Excessive Camber in Prestressed Slab Units	Ariana Morales Rapallo	FDOT	Christina Freeman	Summary
4/30/2005	Field Verification of Camber Estimates for Prestressed Concrete Bridge Girders	Cook, Ron	University of Florida	Ansley, Marcus	BD545-7
2/24/1997	Field Measurement and Evaluation of Time-Dependent Losses in Prestressed Concrete Bridges	Onyemelukwe, Okey	University of Central Florida	Issa, Moussa	0510735

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done, Moving Forward

From Tadros (2011)

"In design, allow for variability of camber by 50%."

"Allowance in design should include flexibility in adjusting the horizontal shear reinforcement and the girder-seat elevations"

From Cook (2005)

"For the influence of the thermal gradient on camber, there was little difference between the empirically corrected camber measurements and the analytically corrected camber measurements in the majority of cases. Either method is suitable for the correction of camber due to thermal gradient effects."

"Guidelines for storage of the girders with instruction of the amount of clearance necessary between the ground and bottom flange should be implemented in order to reduce the effect of differential shrinkage in the field."

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done, Moving Forward

From Rizkalla (2011)

"Whenever practical, camber should be measured before dawn before the sun induces thermal gradients within the girders."

"Girders should be stored with the supports as close to possible to their design bearing locations to minimize camber variability."

From Almohammedi (2019)

"The contractor should update camber, deflection and the road longitudinal profile based on the measured concrete strength to decrease the discrepancy between the design and the actual cambers…"

"…More effectively, the fabricators can provide the contractor with the average camber values for the girders in the storage yard and update the road profile accordingly."

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done, Moving Forward

From Almohammedi (2019)

“Girders should be cast based on a scheduled erection plan to minimize storage time and to reduce the effect of creep and shrinkage on camber prediction.”

“The initial camber and the elastic shortening losses should be measured after moving the girder to the storage yard to eliminate the effect of the friction from the prestressing bed on camber.”

TRANSPORTATION SYMPOSIUM

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Managing & Mitigating: What Can Be Done, Moving Forward

[redacted] Jan-June 2023

NUMBER OF PRESTRESSED CONCRETE PRODUCTS WITH MAJOR DEFECTS FOR THE BI-ANNUAL 6 MONTH PERIOD 1/1 THRU 6/30 Plant No [redacted]

Product Category	Category Group	Product Name	Total Product Produced	Number of Defective by Type*									Total Defective	% Defective
				1	2	3	4	5	6	7	8	9**		
(1) PILES	Group 1A	14" sq. Piles											0	
		18" sq. Piles	6										0	0.00%
		20" sq. Piles											0	
		24" sq. Piles	107										0	0.00%
		30" sq. Piles	165	1									1	0.61%
												Group 1A Totals	1	0.36%
	GP 1B	30"/36" Voided											0	
	GP 1C	Sheet Piles	79										0	0.00%
	GP 1D	Cylinder Piles											0	
Category (1) Products Cast Total			357									Category (1) Defects Total	1	0.28%
(2) BEAMS	Group 2A	AASHTO II											0	
		AASHTO III											0	
		AASHTO IV											0	
												Group 2A Totals	0	
	Group 2B	AASHTO V											0	
		AASHTO VI											0	
												Group 2B Totals	0	
	Group 2C	72 Bulb-T											0	
		78 Bulb-T											0	
												Group 2C Totals	0	
	Group 2D	U Beams											0	
	Group 2E I Beams	36" FIB	40										0	0.00%
		45" FIB	31				1						1	3.23%
		54" FIB											0	
		63" FIB	24										0	0.00%
		72" FIB											0	
		78" FIB	328	1									1	0.30%
		84" FIB											0	
		96" FIB											0	
												Group 2E Totals	2	0.47%
	Group 2F	Other Beams***											0	
Category (2) Products Cast Total			423									Category (2) Defects Total	2	0.47%
(3) SLABS	Group 3A	PS Slab											0	
	Group 3B	PS + PT Slab											0	
Category (3) Products Cast Total			0									Category (3) Defects Total	0	
Totals	Total Products Cast/Defective		780	2	0	0	1	0	0	0	0	0	3	0.38%
(4) SPECIFICATION VIOLATIONS****													0	

*Defective Types: 1 - Spalls, 2 - Chips, 3 - Honeycomb, 4 - Cracks, 5 - Dimensional Deviations, 6 - Bearings
7- Reinforcement Errors, 8 - Materials Defect, 9 - Other Defective

**(9 Other Defective) Attach a Description of the Defective Type(s)

***(Group 2F Other Beams) Attach a Description of the Type(s) of Beam(s)

****((4) Specification Violations) Attach a Description of the Specification Violation(s)

ONLY THE CELLS HIGHLIGHTED YELLOW CAN BE MODIFIED.

PLEASE PROVIDE THE FOLLOWING INFORMATION:

- ▶ YOUR PLANT NAME
- ▶ YOUR PLANT NUMBER
- ▶ TOTAL PRODUCED (AS APPLIES)
- ▶ NUMBER OF MAJOR DEFECTIVE BY TYPE (AS APPLIES)

▶ *Defective Types:
1 - Spalls, 2 - Chips, 3 - Honeycomb, 4 - Cracks,
5 - Dimensional Deviations, 6 - Bearings,
7 - Reinforcment Errors, 8 - Material Defect, 9 - Other Defect

- ▶ **(9 Other Defective) Attach a Description of the Defective Type(s)
- ▶ ***(Group 2F Other Beams) Attach a Description of the Type(s) of Beam(s)
- ▶ ****((4) Specification Violations) Attach a Description of the Specification

TION

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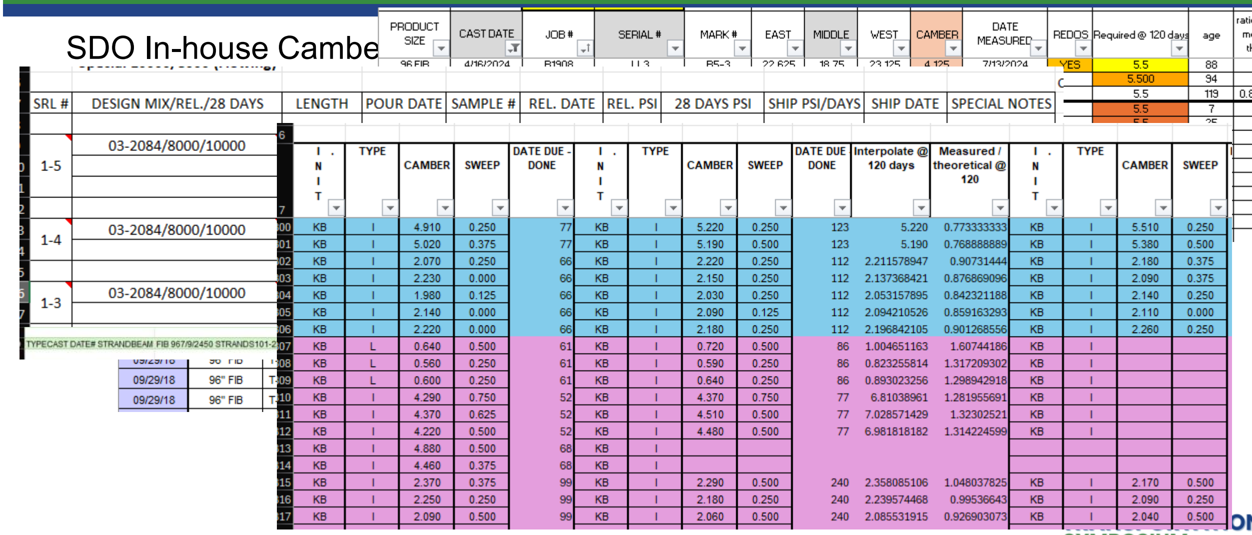
Managing & Mitigating: What Can Be Done, Moving Forward

SDO In-house Cambe



	INIT	TYPE	CAMBER	SWEEP	DATE DUE - DONE	INIT	TYPE	CAMBER	SWEEP	DATE DUE DONE	Interpolate @ 120 days	Measured / theoretical @ 120	INIT	TYPE	CAMBER	SWEEP
00	KB	I	4.910	0.250	77	KB	I	5.220	0.250	123	5.220	0.773333333	KB	I	5.510	0.250
01	KB	I	5.020	0.375	77	KB	I	5.190	0.500	123	5.190	0.768888889	KB	I	5.380	0.500
02	KB	I	2.070	0.250	66	KB	I	2.220	0.250	112	2.211578947	0.90731444	KB	I	2.180	0.375
03	KB	I	2.230	0.000	66	KB	I	2.150	0.250	112	2.137368421	0.876869096	KB	I	2.090	0.375
04	KB	I	1.980	0.125	66	KB	I	2.030	0.250	112	2.053157895	0.842321188	KB	I	2.140	0.250
05	KB	I	2.140	0.000	66	KB	I	2.090	0.125	112	2.094210526	0.859163293	KB	I	2.110	0.000
06	KB	I	2.220	0.000	66	KB	I	2.180	0.250	112	2.196842105	0.901268556	KB	I	2.260	0.250
07	KB	L	0.640	0.500	61	KB	I	0.720	0.500	86	1.004651163	1.60744186	KB	I		
08	KB	L	0.560	0.250	61	KB	I	0.590	0.250	86	0.823255814	1.317209302	KB	I		
09	KB	L	0.600	0.250	61	KB	I	0.640	0.250	86	0.893023256	1.298942918	KB	I		
10	KB	I	4.290	0.750	52	KB	I	4.370	0.750	77	6.81038961	1.281955691	KB	I		
11	KB	I	4.370	0.625	52	KB	I	4.510	0.500	77	7.028571429	1.32302521	KB	I		
12	KB	I	4.220	0.500	52	KB	I	4.480	0.500	77	6.981818182	1.314224599	KB	I		
13	KB	I	4.880	0.500	68	KB	I									
14	KB	I	4.460	0.375	68	KB	I									
15	KB	I	2.370	0.375	99	KB	I	2.290	0.500	240	2.358085106	1.048037825	KB	I	2.170	0.500
16	KB	I	2.250	0.250	99	KB	I	2.180	0.250	240	2.239574468	0.99536643	KB	I	2.090	0.250
17	KB	I	2.090	0.500	99	KB	I	2.060	0.500	240	2.085531915	0.926903073	KB	I	2.040	0.500

SYMPOSIUM

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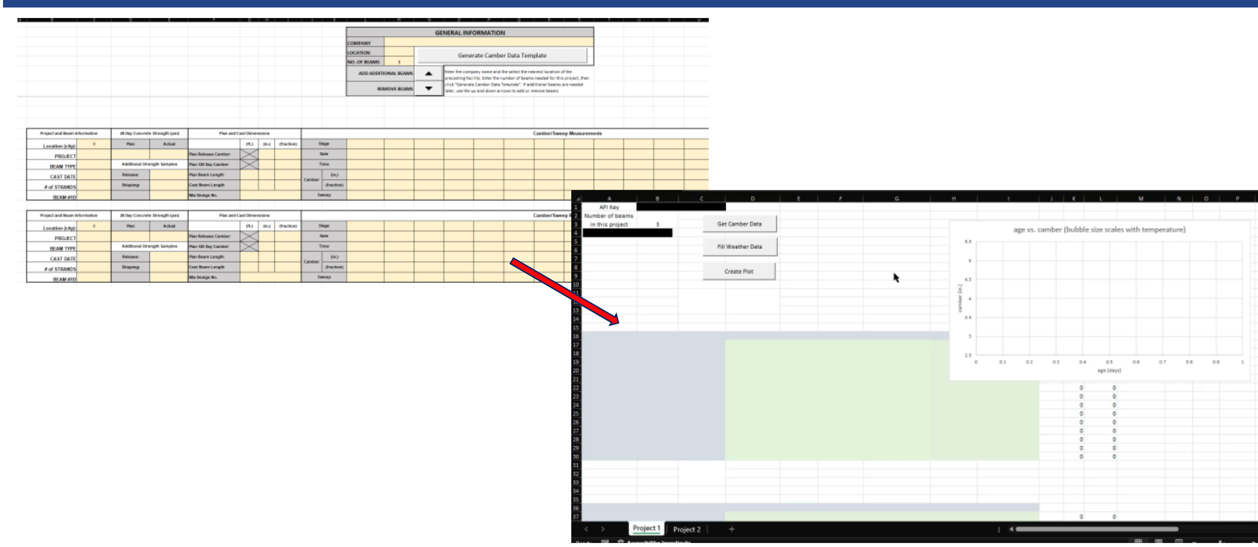
Managing & Mitigating: What Can Be Done, Moving Forward



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References

- Design of Prestressed Concrete (Nilson 1987)
- Field Verification of Camber Estimates for Prestressed Concrete Bridge Girders (Cook 2005)
- Improving the Accuracy of Camber Predictions for Precast Pretensions Concrete Beams (Honarvar 2015)
- Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders, NCHRP rpt 496 (Tadros, Al-Omaishi 2003)
- Predicting Camber, Deflection, and Prestress Losses in Prestressed Concrete Members (Rizkalla 2011)
- Precast, prestressed girder camber variability (Tadros 2011)
- Estimating Camber, Deflection, and Prestress Losses in Precast, Prestressed Bridge Girders (Almohammedi 2019)
- PCI Bridge Design Manual (4th Edition 2023)
- The Design and Analysis of Simple Span Prestressed Concrete Beams Computer Program User's Manual (1994)
- AASHTO LRFD Bridge Design Specifications (1st Edition 1994)

Safety Message

Contact Us

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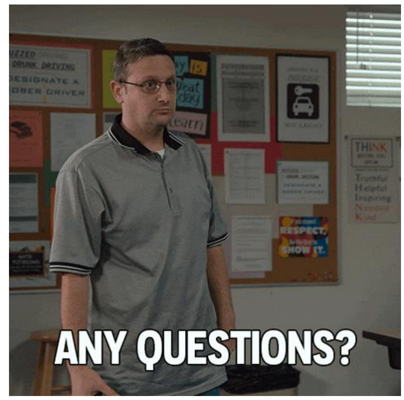
Zachary.Behring@dot.state.fl.us



TRANSPORTATION SYMPOSIUM

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October 28-29, 2025
Orlando, FL

TRANSPORTATION SYMPOSIUM

DEADLINE

Please be sure to **certify your attendance** before leaving this event or no later than **Friday, November 21st**, in order to receive PDH/CEC. Detailed instructions are available on the Transportation Symposium website.

Transportation Symposium Website

SCAN ME

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