Session 36

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Field Verifications of Camber Estimates for Prestressed Concrete Bridge Girders

Topic Description

Accurate camber prediction has the potential to reduce changes and delays in construction by eliminating adjustments in build-up or bearings that are otherwise required to arrive at the correct deck profile. This research was primarily focused on obtaining camber data in order to provide an evaluation of current design methodology. The evaluation was done with the goal of verifying or improving the current design methodology used by the Department for camber estimation.

Speaker Biography

Dr. Ronald A. Cook, P.E., is Professor of Civil Engineering at the University of Florida. He is chairman of the ASCE 7 Wind Load Committee, chairman of ACI 355 Anchorage to Concrete, member of ACI 318 Subcommittee B on Reinforcement and Development and member of the International Association of Bridge and Structural Engineering Working Commission on Concrete Structures. His work experience includes 3 years in construction, 11 years in design, and the past 17 years in engineering education and research.

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Field Verification of Camber Estimates For Prestressed Concrete Bridge Girders

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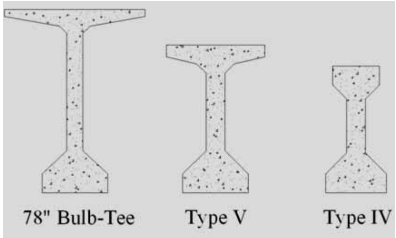
Background

- Camber estimates from FDOT prestressed beam design program had not been field verified.
- Focus was to collect field camber measurements on different types of girders in order to:
  - Verify camber estimates, or
  - Provide recommendations for changes to the FDOT program

Scope of Project

- Collect field camber measurements on:
  - Six 78" Bulb-Tee girders
    - 162 ft. length
  - Four AASHTO Type V girders
    - 81 ft. length
  - Three AASHTO Type IV girders
    - 91 ft. length
- Supplemental materials testing



Outline of Presentation

- Problems encountered during field measurement
- Field measurements and comparison to FDOT predicted camber
- Supplemental materials testing
- Summary

Problems Encountered During Field Measurement

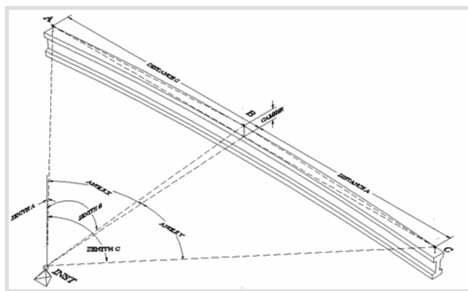
- Method of measurement
  - Surveying theodolite
  - Pro-Level[TM]
  - Comparison of methods to initial camber measured directly from the casting bed
- Thermal effects

Surveying Theodolite Method for Field Camber Measurements

- Optical targets were mounted at endpoints and at mid-span.
- 24 angular readings were made for each camber measurement.

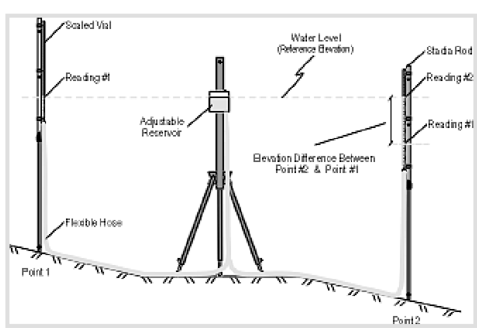
Surveying Theodolite Method for Field Camber Measurements

- Angular readings were used to triangulate the relative height of each target.
  - Using 3-point resection analysis.
- Very time-consuming and indirect.



PRO-LEVEL™ Method for Field Camber Measurements

- Targets mounted at endpoints and at mid-span.
- Elevation readings relative to fixed reservoir height.
- Easy and fast to use



Comparison of Initial Camber Measurements

- Zero readings for all methods were made before prestressing tendons were cut
- Results of theodolite and Pro-Level were compared to Vernier caliper measurements made directly from the casting bed before and after detensioning

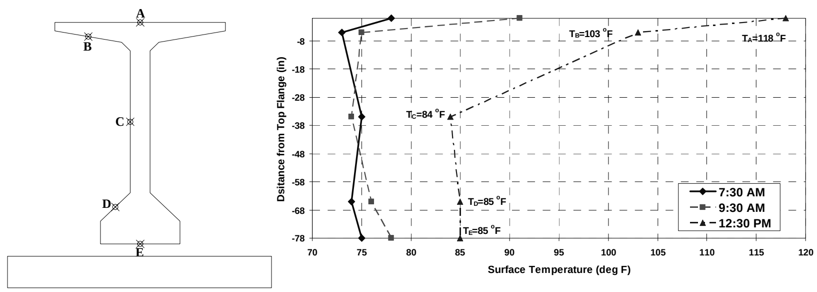
Beam No.	*Pro-Level*™ (in)	Direct Measurement (in)	Difference (in)	Percent Difference (%)
TYPE V 1	0.85	0.82	0.03	3.66%
TYPE V 2	0.90	0.85	0.05	5.88%
TYPE V 3	0.85	0.85	0.00	0.00%
TYPE V 4	0.70	0.65	0.05	7.69%

Beam No.	Surveying [illegible]	Direct [illegible]	[illegible]	Percent [illegible]
FLBT 1				
FLBT 2				
FLBT 3				
FLBT 4				
FLBT 5				
FLBT 6	[illegible]	[illegible]	[illegible]	[illegible]
TYPE IV 1	0.65	0.68	-0.03	-4.71%
TYPE IV 2	0.61	0.62	0.00	-0.65%
TYPE IV 3	0.67	0.64	0.03	3.91%

Thermal Effects

- 14-day camber measurement on 78” Bulb-Tee girders was less than the previous measurement.
  - Significance of thermal effects on camber
  - Cambers were measured in the morning, but couldn’t avoid summer heat.
- An infrared temperature sensor was used to measure the surface temperature at several points along the profile at the mid-span.

Field Temperature Measurements



- non-linear
- increased during the day

Time	Field Measured Camber (in)
7:30 AM	2.99
9:30 AM	3.13
12:30 PM	3.65

Thermal Effects

- Thermal effects were accounted for by field temperature measurements made three times in a single day:
  - Empirical thermal analysis
    - Based on a University of Texas study.
    - Relationship between change in temperature profile and change in camber.
  - Analytical thermal analysis
    - Using field temperature measurements and theoretical relationships.
    - Based on recommendations of *NCHRP Report 276*

Empirical Thermal Analysis

- Approximated a linear thermal gradient.
  - Assumed negative thermal gradient did not cause deflection (i.e. only $\Delta T \geq 0$ was considered).
- Normalized subsequent camber readings to (1st) morning reading.
  - Represented as a percentage increase from the morning reading.

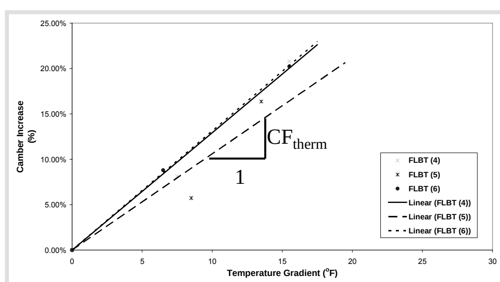
$$\Delta T = \frac{T_A + T_B}{2} - \frac{T_D + T_E}{2}$$

Example Field Measurements

$$\Delta C\% = \frac{C_i - C_o}{C_o}$$

Empirical Thermal Analysis

- Plotted points for each field measurement.
- Calculated correction factor.
  - Slope of $\Delta C\%$ vs. ΔT.
  - Forced through origin.



– $C_{corr} = C_{field} - (C_{field} \cdot CF_{therm} \cdot \Delta T)$

Analytical Thermal Analysis

- Based on recommendations of *NCHRP Report 276.*
  - AASHTO report on thermal effects in superstructures.
- Thermal coefficient of concrete from Table 5 of *NCHRP Report 276*.
  - Based on coarse aggregate type.
  - Granite:
    - $\alpha = 0.0000053\ 1/^{o}F$

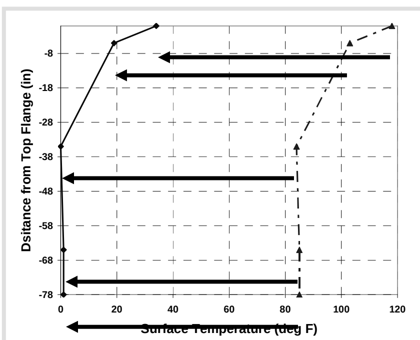
Table C-3 Coefficients of thermal expansion based on aggregate base (thermal coefficient of concrete based on fine and coarse aggregates).

AGGREGATE TYPE	THERMAL COEFFICIENT OF CONCRETE* (0.000001 per °F)
Quartzite	7.1
Quartz	6.4
Sandstone	6.5
Gravel	6.9
Granite	5.3
Dolerite	5.3
Basalt	5.0
Marble	2.4–4.1
Limestone	4.0

* Based on fine and coarse aggregates

Analytical Thermal Analysis

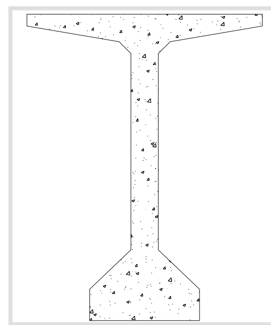
- Temperature profile normalized to smallest temperature reading to obtain thermal gradient.
  - Gradient is a function of depth, $\Delta T(z)$.



Analytical Thermal Analysis

- Gradient used to calculate thermally induced stresses.
  - Function of depth, *z*.
- Width of member is a piecewise linear function of depth, *b(z).*
  - Dependent on shape of girder.

$$\sigma_T(z) = E_c \cdot \alpha \cdot \Delta T(z)$$



Analytical Thermal Analysis

- Integrate to determine the internal moment caused by the thermally induced stresses.
- Calculate camber due to internal moment.
  - Assuming a constant thermal gradient over the length of the member.
- Subtract Δ_T from field measured camber.

$$M_{\text{int}} = \int_0^H \sigma_T(z) \cdot b(z) \cdot (z - c) \cdot dz$$

$$\Delta_T = \frac{M_{\text{int}} \cdot L^2}{8 \cdot E_c \cdot I_g}$$

$$C_{corr} = C_{field} - \Delta_T$$

Thermal Analyses

- There was little difference between results from:
  - The empirical thermal analysis
  - The analytical thermal analysis
- The analytical thermal analysis was used as the primary means for the camber corrections

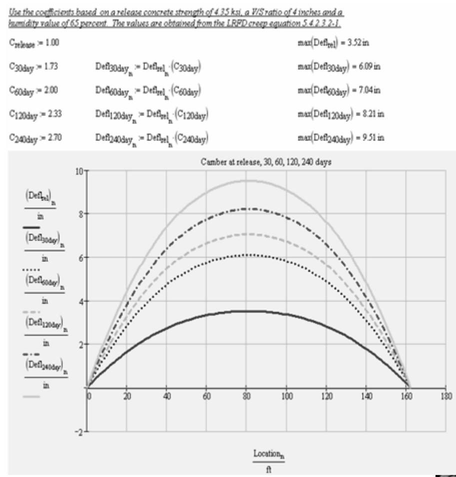
Date	Time	Field Camber (in)	Top Flange Temp (^oF)	Bottom Flange Temp (^oF)	Web Temp (^oF)	Top Bulb Temp (^oF)	Bottom Bulb Temp (^oF)	ΔT (^oF)	Empirical Corrected Camber (in)	Analytical Corrected Camber (in)
6/7/2004	7:30 AM	2.99	78	73	75	74	75	1	2.96	2.97
6/7/2004	9:30 AM	3.13	91	75	74	76	78	6	2.96	2.98
6/7/2004	12:30 PM	3.65	118	103	84	85	85	25.5	2.81	2.79

FDOT Camber Prediction

- Based on *LRFD PSBeam* v.1.85
  - MathCAD worksheet
  - Calculations outlined by LRFD Specification
- Camber calculation method:
  - Uses refined prestress loss calculation method
    - AASHTO LRFD Specification: Section 5.9.5.4
  - Calculates camber by:
    - Computing net moment due to self-weight and prestressing force
    - Divide net moment by $E \cdot I$ to obtain curvature
    - Integrating the curvature twice to obtain the deflection

FDOT *PSBeam* v.1.85 Camber Prediction

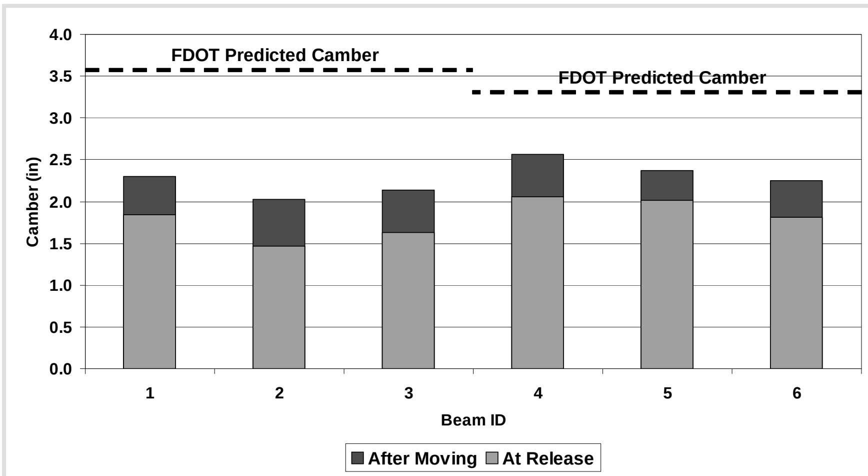
- Uses multipliers to estimate long-term camber growth.
  - Applied to calculated camber at release.
  - Multipliers based on:
    - LRFD creep coefficients.
    - Older design program.



78” Bulb-Tee Camber

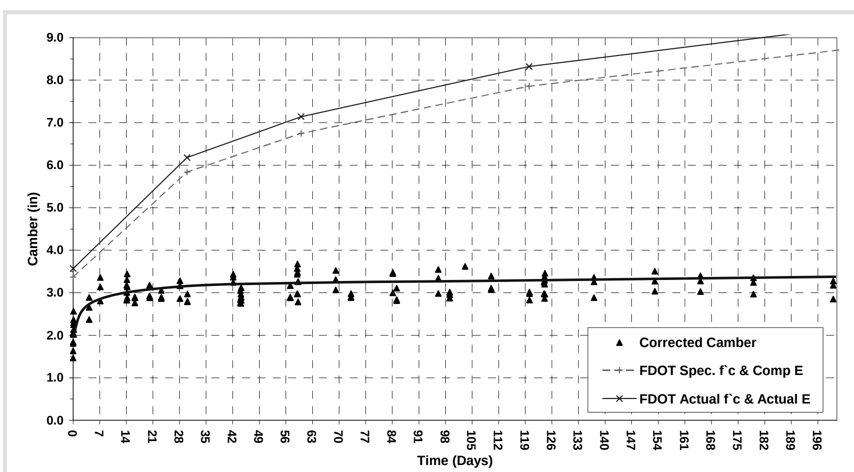
- The 162’-span 78” Bulb-Tee camber measurements were substantially less than what was predicted by the FDOT program
  - 55% of the predicted values at transfer
  - 35% of the predicted values at 200-days

78” Bulb-Tee Camber



Note: time between release and relocation = 3 hours.

78” Bulb-Tee Camber

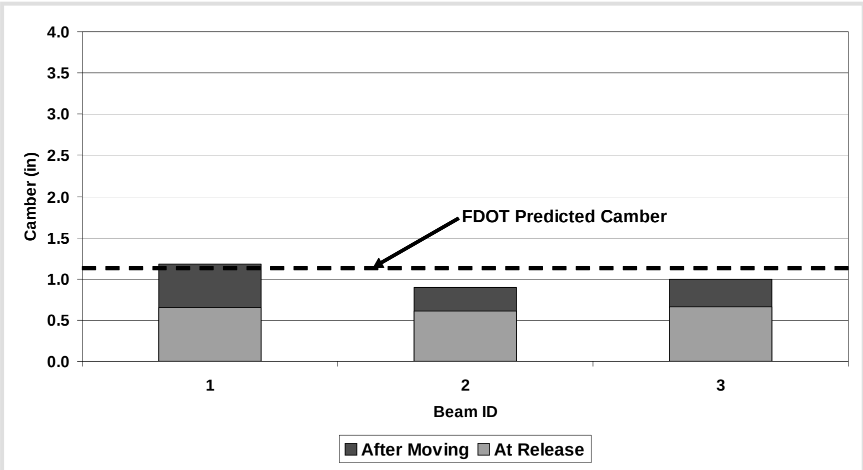


Note: Cambers are analytically corrected for thermal effects.

AASHTO Type IV Camber

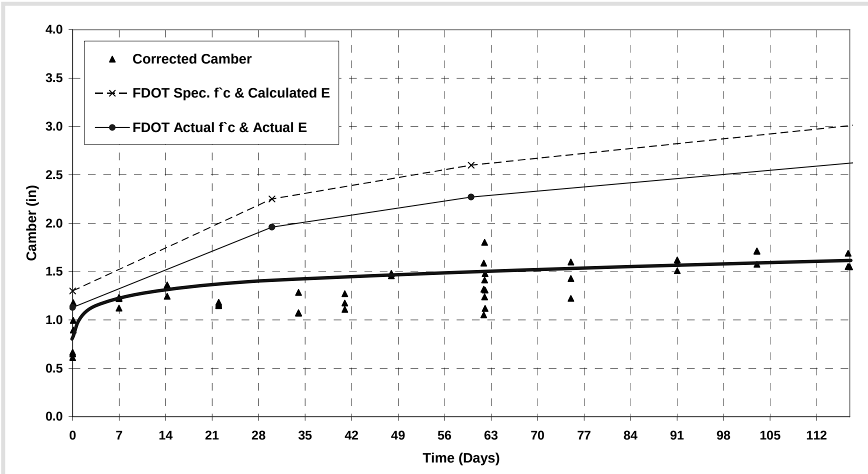
- The 91'-span AASHTO Type IV camber measurements were generally less than what was predicted by the FDOT program
  - About the same as the predicted values after the girders had been relocated to up to 14 days.
  - 60% of the predicted values at 120-days

AASHTO Type IV Camber



Note: time between release and relocation = 2 hours.

AASHTO Type IV Camber



Note: Cambers are analytically corrected for thermal effects.

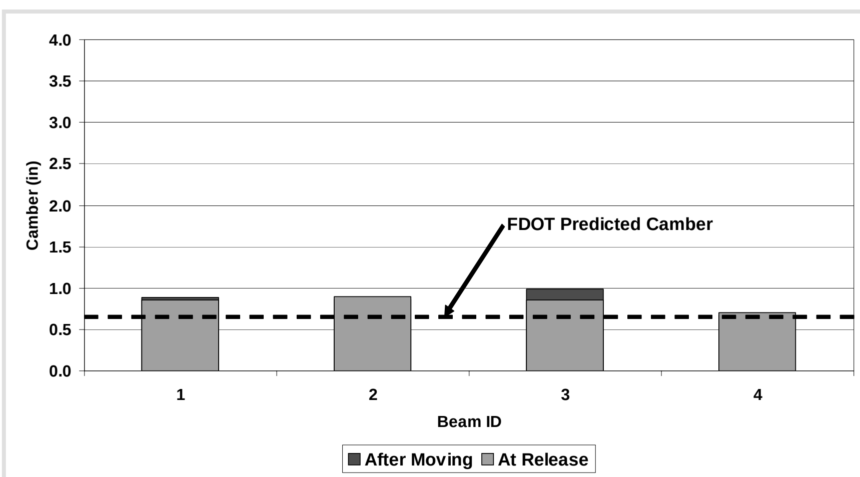
AASHTO Type IV Camber

- Divergence of actual camber growth from predicted camber growth at 14-days could have been caused by lack of ventilation around bottom flange.
  - Causing differential shrinkage and warping.

AASHTO Type V Camber

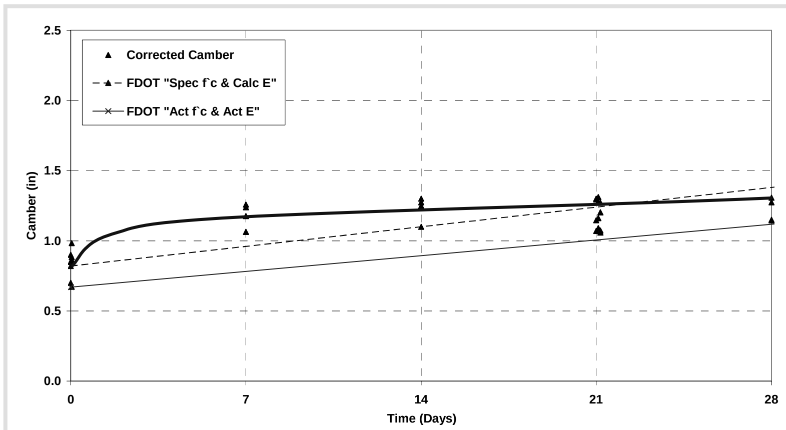
- The 81'-span AASHTO Type V camber measurements were very close to what was predicted by the FDOT program.
- Monitored for 28-days past the transfer of the prestress force.

AASHTO Type V Camber



Note: time between release and relocation = 1 hour.

AASHTO Type V Camber



Note: Cambers are analytically corrected for thermal effects.

LRFD Creep Coefficient

- Ratio of creep strain to elastic strain.
- Collins and Mitchell (1991):

$$\phi(t,t_i) = 3.5 \cdot k_c \cdot k_f \cdot \left(1.58 - \frac{H}{120}\right) \cdot t_i^{-0.118} \cdot \frac{(t-t_i)^{0.6}}{10 + (t-t_i)^{0.6}}$$

  - k_f accounts for effect of high-strength concrete.
  - k_c accounts for effects of V/S ratio.
- AASHTO LRFD section 5.4.2.3.2
  - Doesn't give guidelines how to apply creep coefficient to camber calculations.

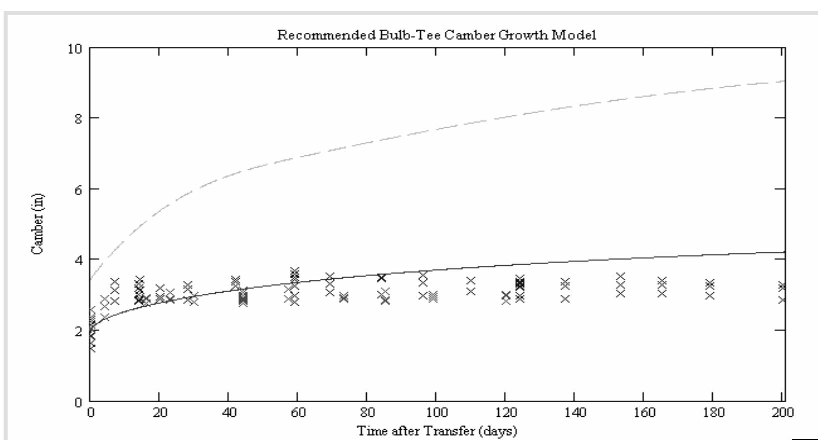
Recommended Camber Growth Model

- Based on Nilson proposal that creep coefficient be applied to long-term loading due to:
  - Prestressing force
  - Member self-weight

$$\Delta = \Delta_{pe} + \frac{\Delta_{pi} + \Delta_{pe}}{2} \cdot \phi(t,t_i) - \Delta_o\left[1 + \phi(t,t_i)\right]$$

Time After Transfer (days)	Mean Interpolated Field Camber (in)	Mean FDOT Predicted Camber (in)	% Difference	Recommended Method (in)	% Difference
0	1.804	3.44	90.69%	1.924	6.65%
30	2.996	5.95	98.60%	2.952	-1.47%
60	3.044	6.88	126.02%	3.348	9.99%
120	3.068	8.015	161.25%	3.83	24.84%
200	3.102	8.655	179.01%	4.336	39.78%

Recommended Camber Growth Model



Supplemental Materials Testing

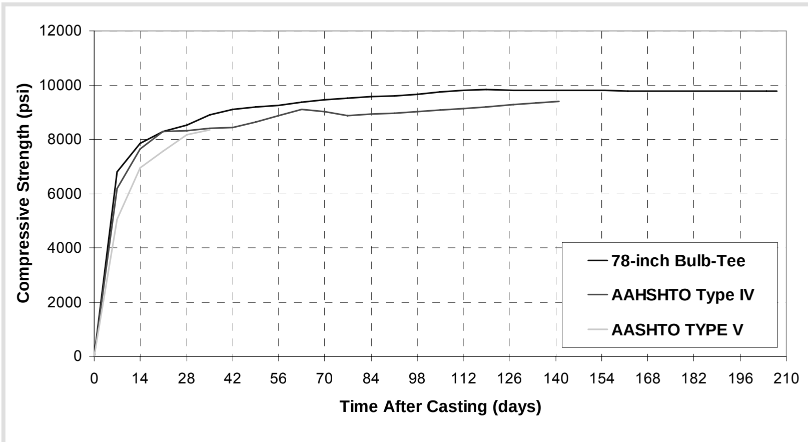
- Periodic materials testing was performed on test cylinders made from each pour of girders.

Girder Type	Pour A	Pour B
78" Bulb-Tee	Girders 1-3	Girders 4-6
	35-4x8 Cylinders	30-4x8 Cylinders
	18-6x12 Cylinders	3-6x12 Cylinders
AASHTO Type IV	Girders 1-3	-N/A-
	35-4x8 Cylinders	-N/A-
	9-6x12 Cylinders	-N/A-
AASHTO Type V	Girders 1-2	Girders 3-4
	15-4x8 Cylinders	15-4x8 Cylinders
	0-6x12 Cylinders	0-6x12 Cylinders

Supplemental Materials Testing

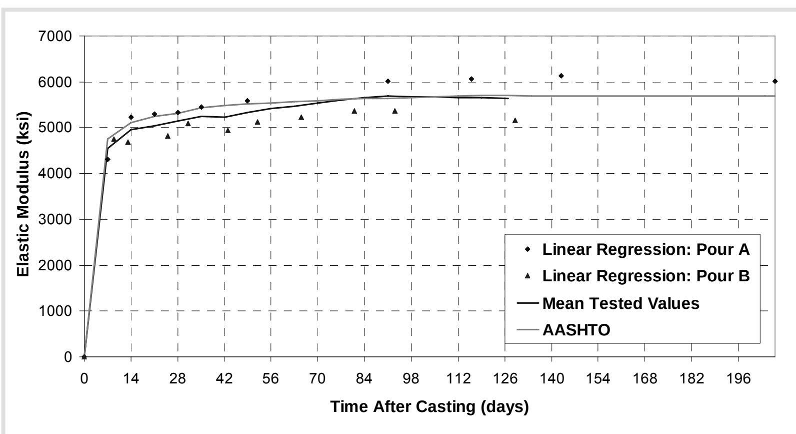
- Cylinders were field cured.
  - Ensured material test data accurately represented actual material properties of girders
- MTS® cylinder testing apparatus.
  - Computer controlled
  - Extensometers collected strain data

Compressive Strength Summary

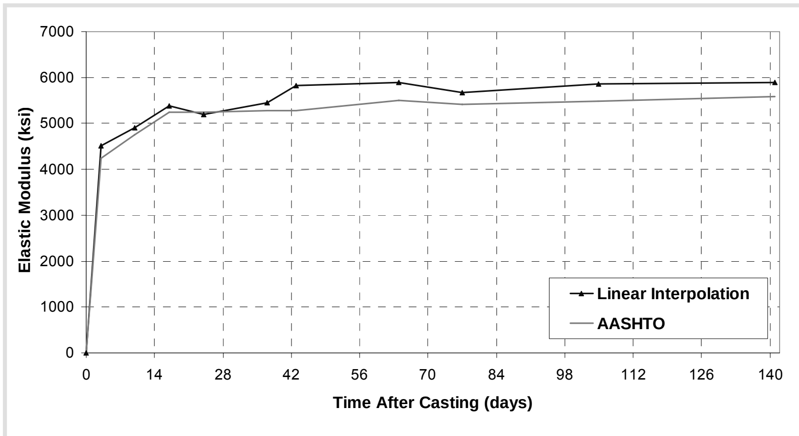


Note: Plot represents mean tested values.

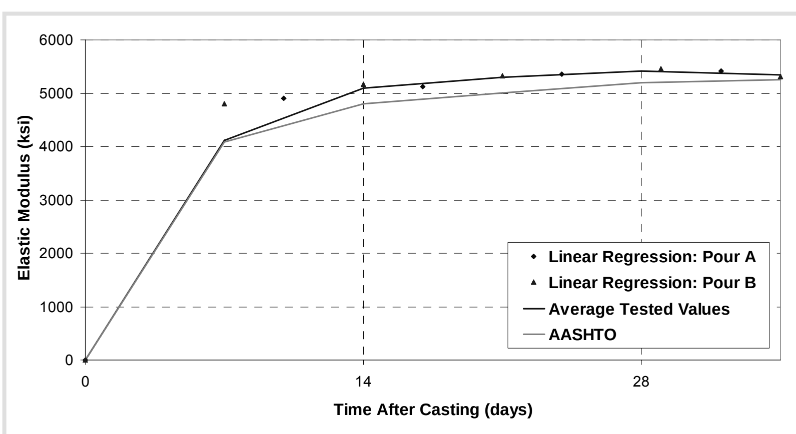
78" Bulb-Tee Elastic Modulus



Type IV Elastic Modulus



Type V Elastic Modulus



Summary

- Recommended camber growth model should be implemented in the FDOT design program.
- There was no significant difference between the empirical and analytical thermal analyses regarding calculation of camber from temperature differential
- The AASHTO method for calculating the elastic modulus is OK