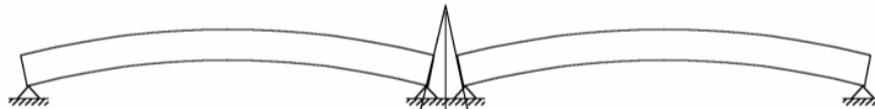




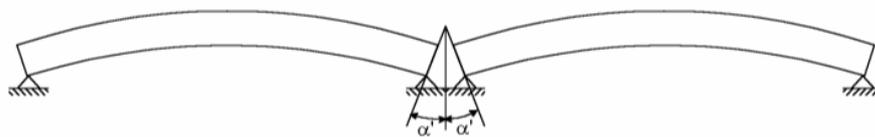
# THE CONTINUITY CONUNDRUM

A PRECAST SUPPLIER PERSPECTIVE

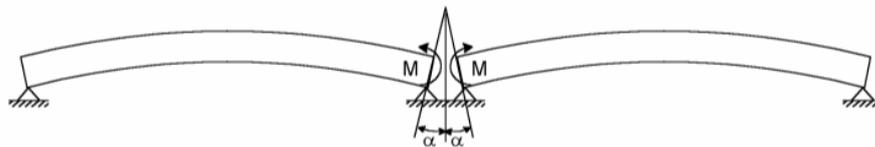
## P/S Creep and Restraint Moments



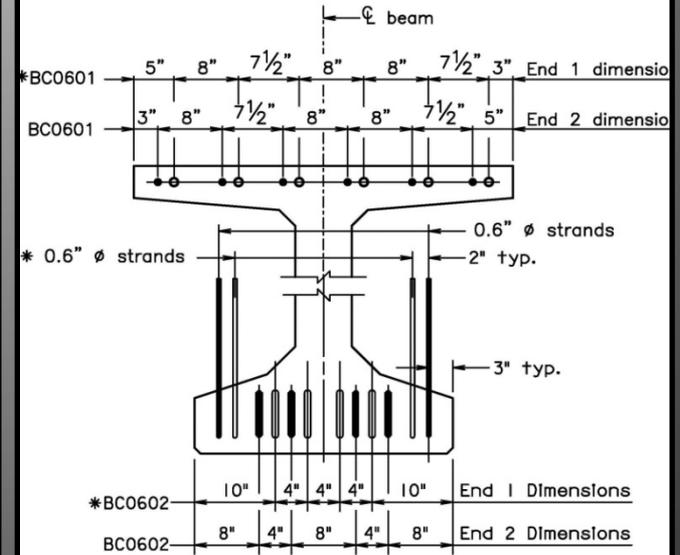
a) Initial Deformation



b) Final "Free" Deformation (simple-span)



c) Final Deformation and Associated Restraint Moments for Simple Spans Made Continuous



\* Bars are from beam in adjacent span

END VIEW AT CLOSURE DIAPHRAGM

Al Patel, PE Clark-Nexsen

Rodney Davis, PhD, PE Bayshore Concrete Products

Fatmir Menkulasi, PhD, PE La-Tech University

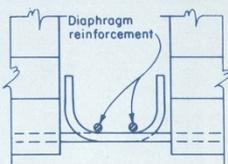
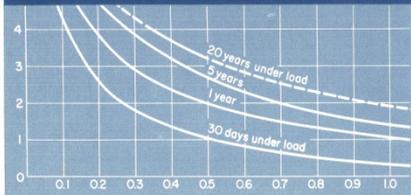
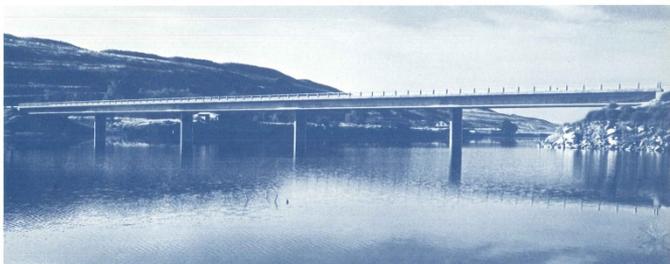
JP Binard, PE Bayshore Concrete Products



# HISTORY

ENGINEERING BULLETIN

## Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders



PRECAST CONCRETE prestressed units  
3  
Portland Cement Association August 1960

PORTLAND CEMENT ASSOCIATION

# NCHRP

## REPORT 519

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

### Connection of Simple-Span Precast Concrete Girders for Continuity

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES



# CURRENT CODE PROVISION

- AASHTO LRFD SPECIFICATIONS:

## *5.14.1.4.4—Age of Girder When Continuity Is Established*

The minimum age of the precast girder when continuity is established should be specified in the contract documents. This age shall be used for calculating restraint moments due to creep and shrinkage. If no age is specified, a reasonable, but conservative estimate of the time continuity is established shall be used for all calculations of restraint moments.

The following simplification may be applied if acceptable to the Owner and if the contract documents require a minimum girder age of at least 90 days when continuity is established:

## *5.14.1.4.5—Degree of Continuity at Various Limit States*

Both a positive and negative moment connection, as specified in Articles 5.14.1.4.8 and 5.14.1.4.9, are required for all continuity diaphragms, regardless of the degree of continuity as defined in this Article.

The connection between precast girders at a continuity diaphragm shall be considered fully effective if either of the following are satisfied:

- The calculated stress at the bottom of the continuity diaphragm for the combination of superimposed permanent loads, settlement, creep, shrinkage, 50 percent live load and temperature gradient, if applicable, is compressive.
- The contract documents require that the age of the precast girders shall be at least 90 days when continuity is established and the design simplifications of Article 5.14.1.4.4 are used.



## CLAUSE:

- 50% Live Load
- Temperature Gradient
- Superimposed Comp DL
- Creep
- Shrinkage
- Settlement, *not considered*

COMPRESSIVE?



# DESIGN

11. The design is based on a minimum of 90 days between release of strands and casting of closure diaphragm.

**Loads**

**Dead Load, non-composite**

Self-weight multiplier: 1 (default=1.0)

Diaphragms:

Locations:  L/4  L/3  L/2  Other: 0 FT

Weight: 1 Kip

Other uniform dead load: 0.2 klf/beam

Restraining Mom:

Ignore

Compute:

Distrib Method: Equal

No. Barriers: 2

Barrier wt: 0.5 klf/each

Constant: 0.15 klf/beam

Variable: 0.015 ksf

Distrib Method: Beam Spec

Other Uniform: 0 klf/beam

**Live Load**

**Vehicle 1**

Include LL Multiplier: 1 Properties... DLA/Impact:

ID: HL-93  Compute

Specify: 0.33

**Vehicle 2**

Include LL Multiplier: 1 Properties... DLA/Impact:

ID: NONE  Compute:

Specify: 0.33

Combine Vehicles 1 and 2 by:

Adopt Governing Results

LRFD 4.6.2.2.5 (Vehicle 2 is Overload)

Do Not Combine Vehicle Results

Pedestrian: 0 klf/beam

**Deflection Criteria**

1/800

1/1000

User-Defined: 1/1000

**Live Load DF**

Compute

Specify:

DF-H: 1 lanes

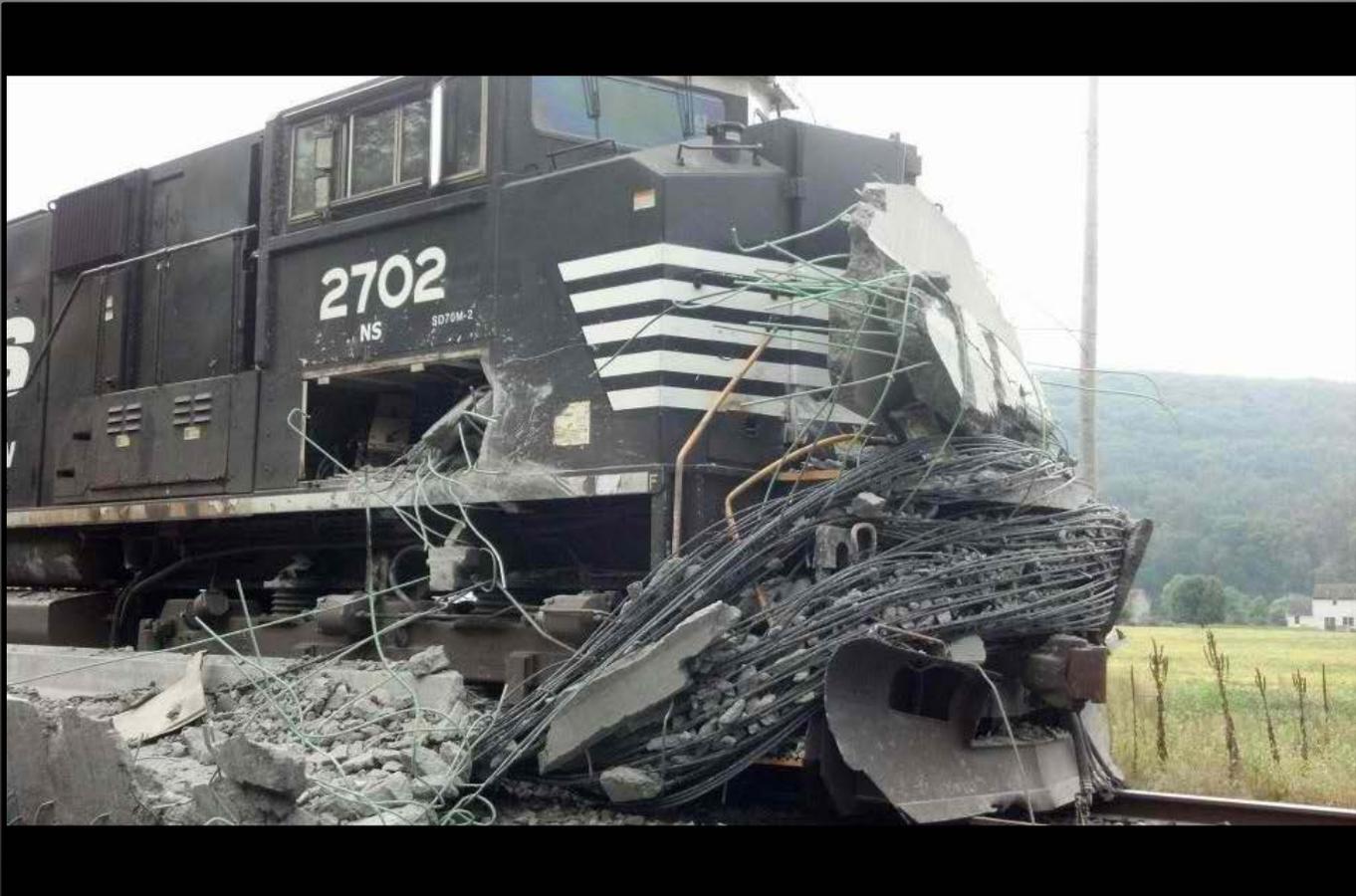
DF-V: 1 lanes

DF-F: 1 lanes

OK Cancel

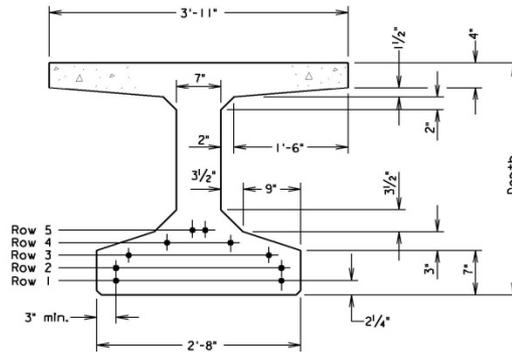


# PROBLEM?





# PARAMETERS:



Maximum number of strands in row number 1: 14  
 2: 14  
 3: 12  
 4: 6  
 5 and higher: 2

- PCBT 45, 69, & 95
- Solar Radiation, Zone 3
- 2 Span, 3-Span, 4-Span

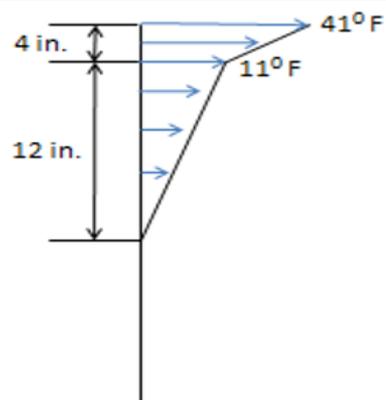
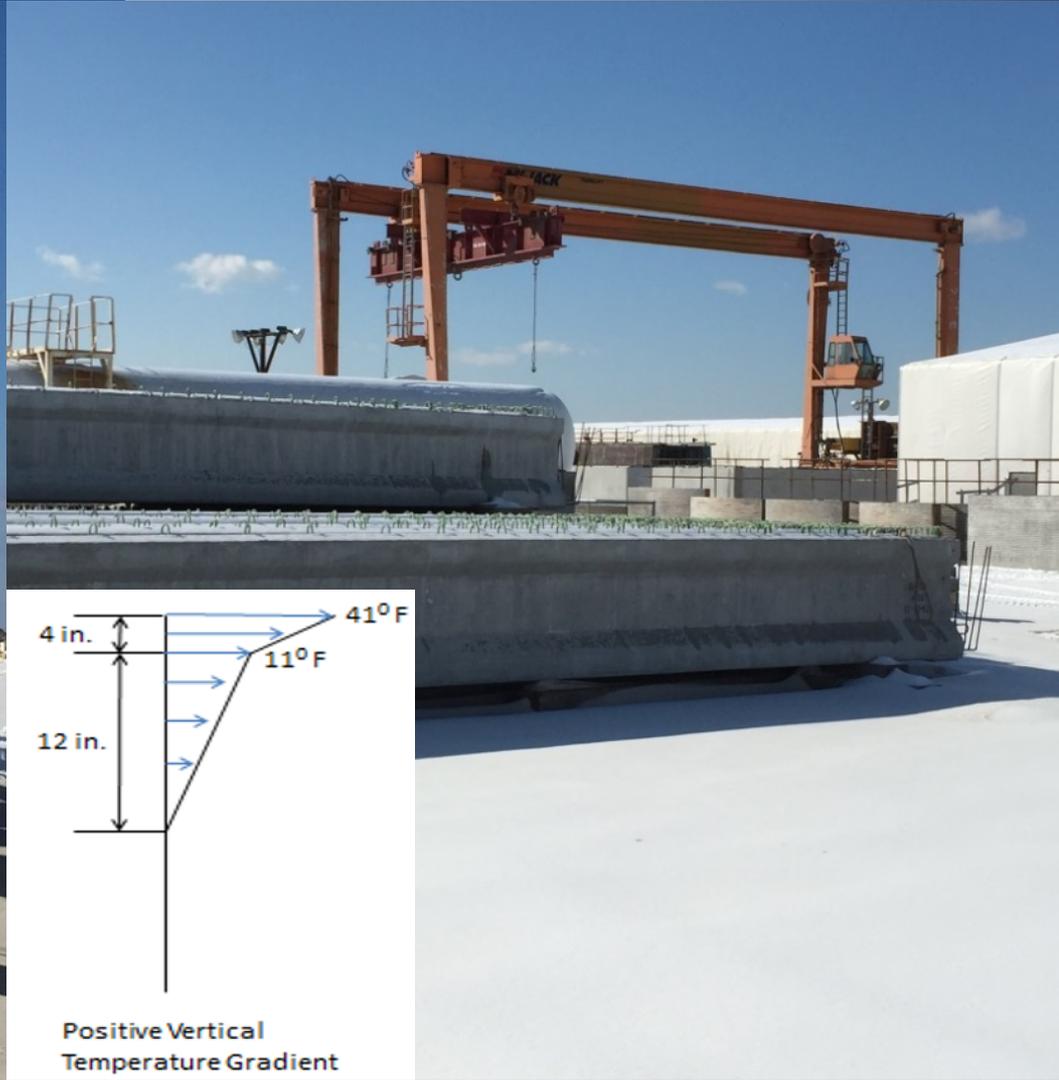
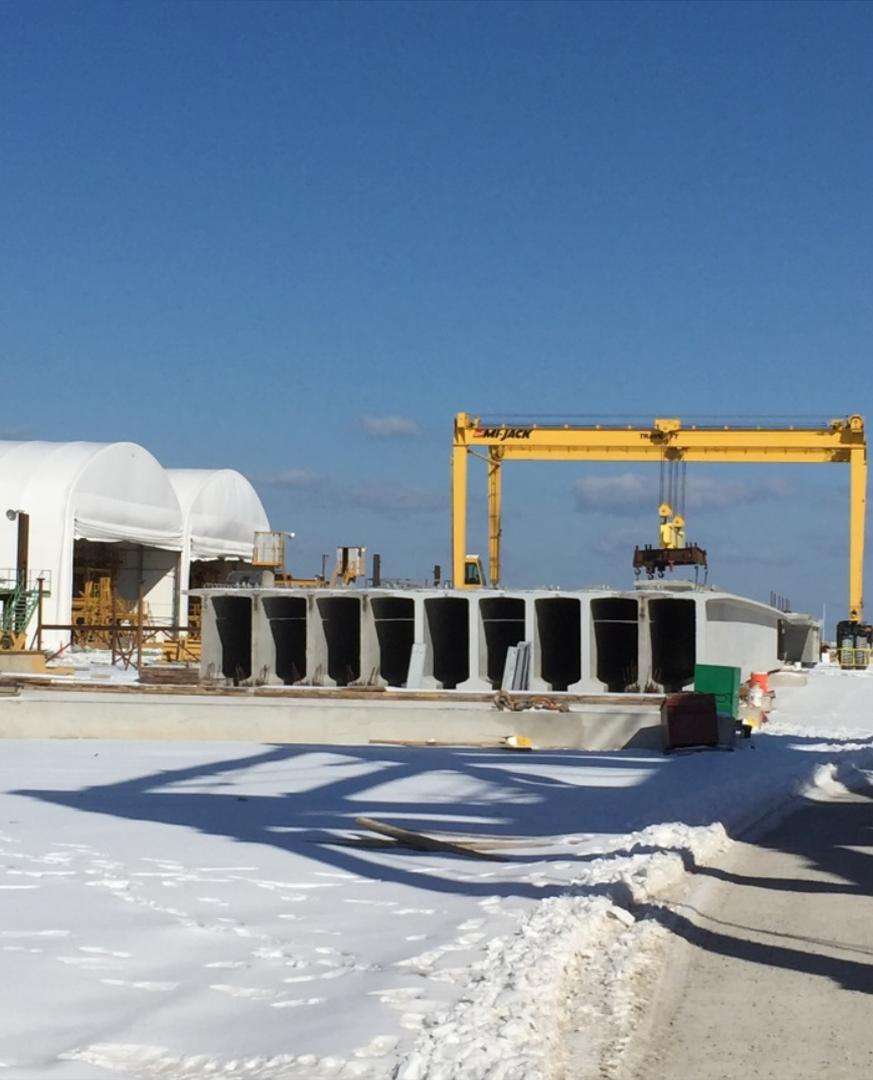
| Beam Designation | Depth<br>D<br>(in) | Area<br>A<br>(in <sup>2</sup> ) | Volume to Surface Ratio<br>V/S<br>(in) | Centroid to Bottom<br>y <sub>b</sub><br>(in) | Moment of Inertia<br>I<br>(x 10 <sup>3</sup> in <sup>4</sup> ) | Section Modulus                        |   | Weight @ 150 pcf<br>(lbs./lin. ft.) |
|------------------|--------------------|---------------------------------|--|--|--|--|---|-------------------------------------|
|                  |                    |                                 |  |  |  | S <sub>top</sub><br>(in <sup>3</sup> ) | S <sub>bottom</sub><br>(in <sup>3</sup> ) |                                     |
| PCBT-29          | 29                 | 634.7                           | 3.40                                   | 14.66  | 66.8   | 4658                                   | 4557                                      | 661                                 |
| PCBT-37          | 37                 | 690.7                           | 3.41                                   | 18.43  | 126.0  | 6785                                   | 6837                                      | 720                                 |
| PCBT-45          | 45                 | 746.7                           | 3.41                                   | 22.23  | 207.3  | 9104                                   | 9325                                      | 778                                 |
| PCBT-53          | 53                 | 802.7                           | 3.42                                   | 26.06  | 312.4  | 11596                                  | 11988                                     | 836                                 |
| PCBT-61          | 61                 | 858.7                           | 3.42                                   | 29.92  | 443.1  | 14257                                  | 14810                                     | 894                                 |
| PCBT-69          | 69                 | 914.7                           | 3.43                                   | 33.79  | 601.3  | 17078                                  | 17795                                     | 953                                 |
| PCBT-77          | 77                 | 970.7                           | 3.43                                   | 37.67  | 788.7  | 20053                                  | 20937                                     | 1011                                |
| PCBT-85          | 85                 | 1026.7                          | 3.44                                   | 41.57  | 1007.2   | 23191                                  | 24229                                     | 1070                                |
| PCBT-93          | 93                 | 1082.7                          | 3.44                                   | 45.48  | 1258.5   | 26484                                  | 27672                                     | 1128                                |

**PRESTRESSED CONCRETE  
 BULB-T'S - LRFD  
 SECTION PROPERTIES**

VOL. V - PART 2  
 DATE: 08Oct2010  
 SHEET 3 of 15  
 FILE NO. 12.03-3



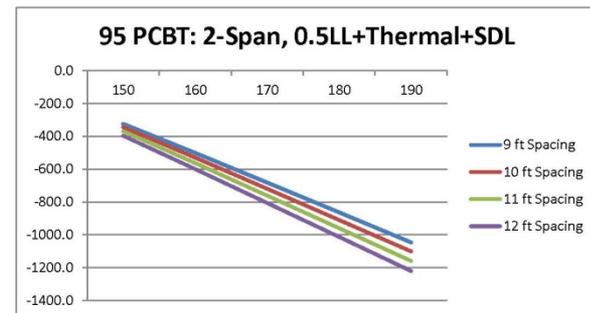
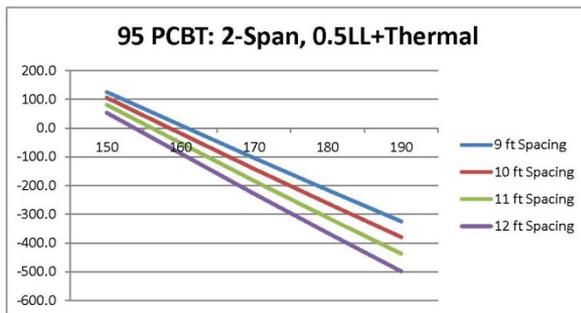
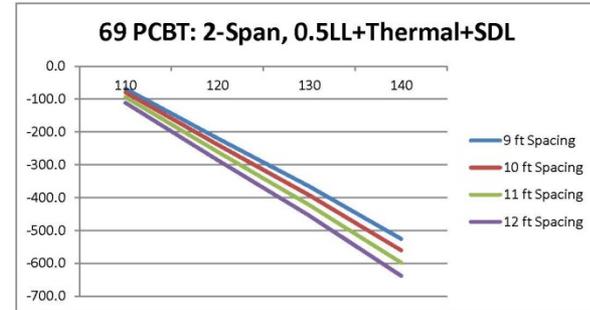
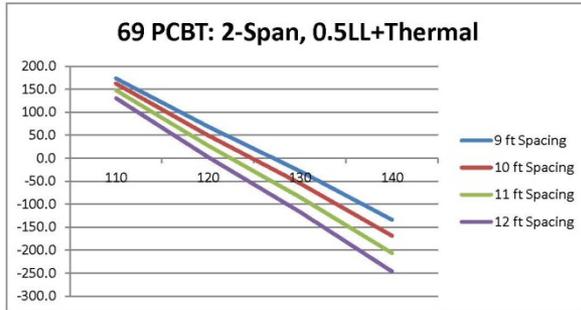
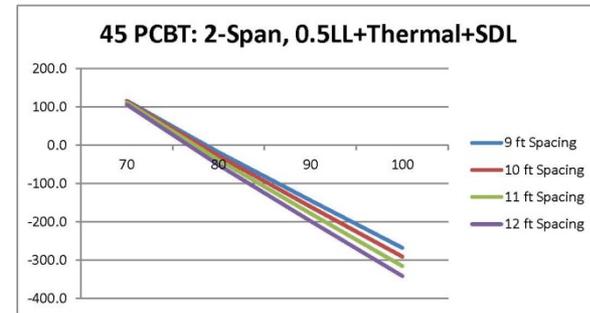
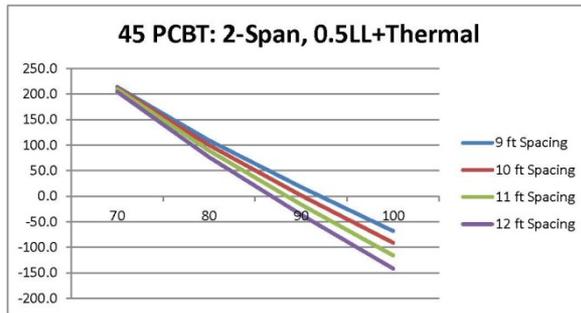
# THERMAL



Positive Vertical Temperature Gradient

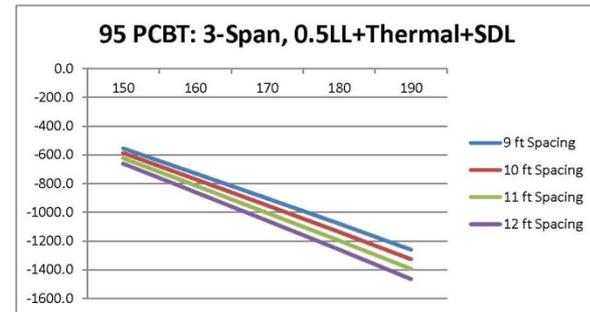
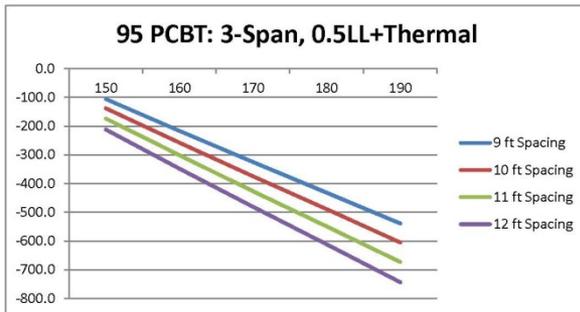
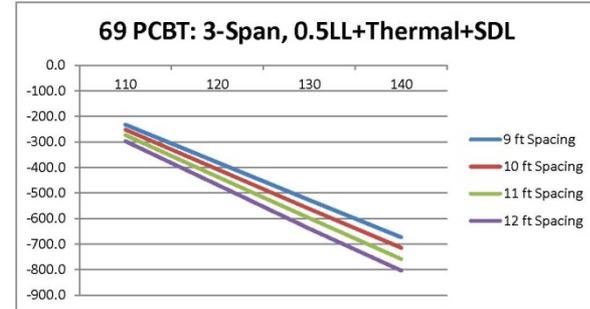
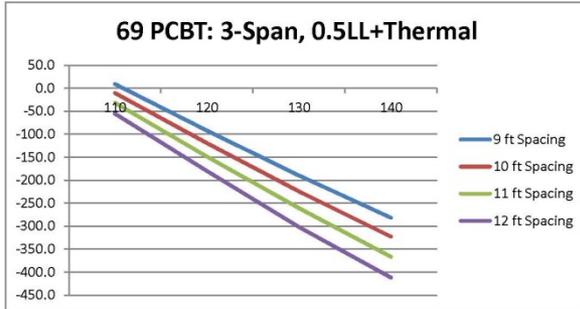
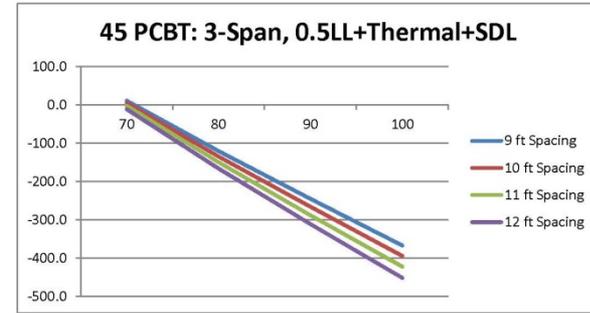
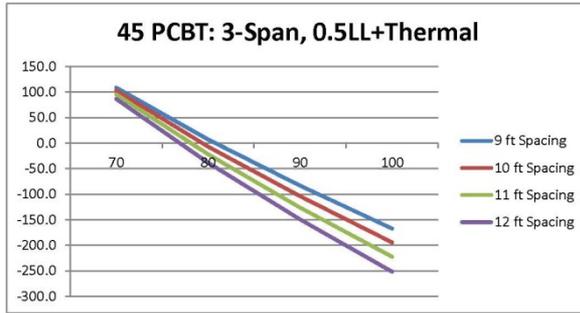


# 2-SPAN: THERMAL + LL , + SDL



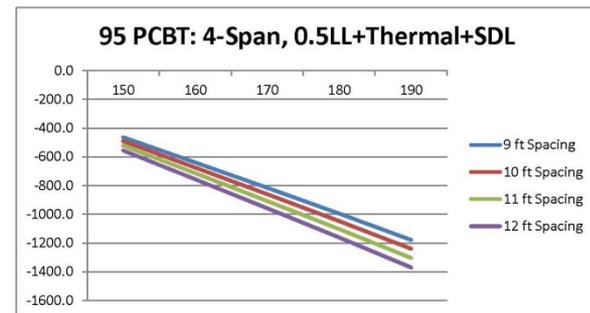
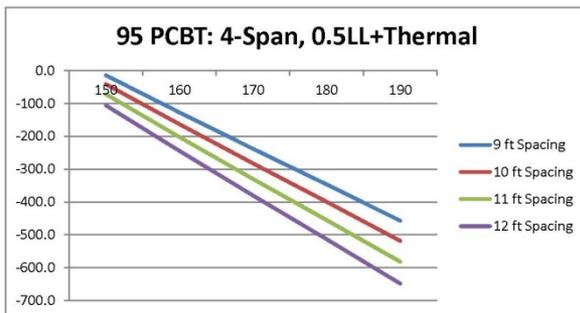
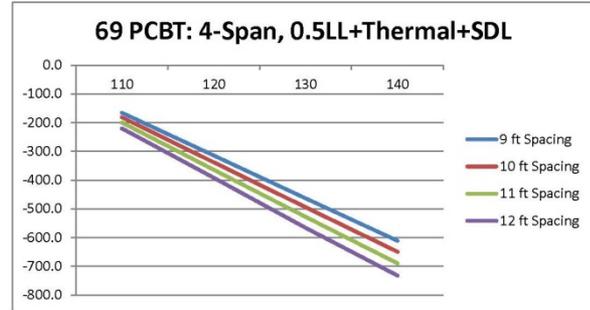
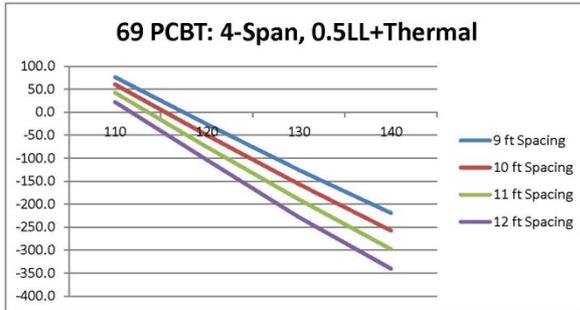
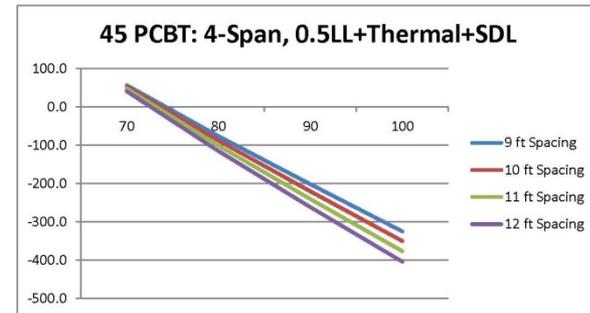
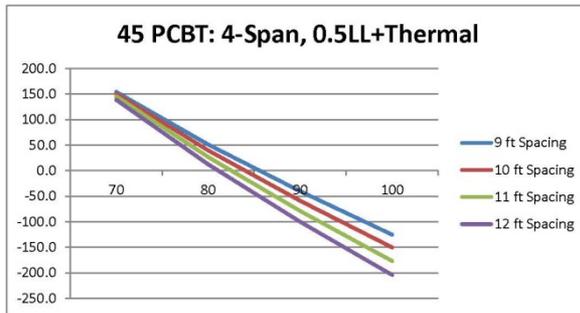


# 3-SPAN: THERMAL + LL , + SDL





# 4-SPAN: THERMAL + LL , + SDL





## SIMPLIFIED CLAUSE:

- 50% Live Load
- Temperature Gradient
- Superimposed Comp DL
- Creep
- Shrinkage
- Settlement, *not considered*

COMPRESSIVE,  
TYPICAL

INVESTIGATE



# CREEP & SHRINKAGE

- AASHTO LRFD SPECIFICATIONS

The creep coefficient may be taken as:

$$\Psi(t, t_i) = 1.9k_s k_{hc} k_f k_{td} t_i^{-0.118} \quad (5.4.2.3.2-1)$$

$$k_{hc} = 1.56 - 0.008H \quad (5.4.2.3.2-3)$$

$$k_f = \frac{5}{1 + f'_{ci}} \quad (5.4.2.3.2-4)$$

$$k_{td} = \left( \frac{t}{61 - 4f'_{ci} + t} \right) \quad (5.4.2.3.2-5)$$

For creep:

$$k_c = \left[ \frac{\frac{t}{26e^{0.36(V/S)} + t}}{\frac{t}{45 + t}} \right] \left[ \frac{1.80 + 1.77e^{-0.54(V/S)}}{2.587} \right] \quad (C5.4.2.3.2-1)$$

## 5.4.2.3.3—Shrinkage

For concretes devoid of shrinkage-prone aggregates, the strain due to shrinkage,  $\epsilon_{sh}$ , at time,  $t$ , may be taken as:

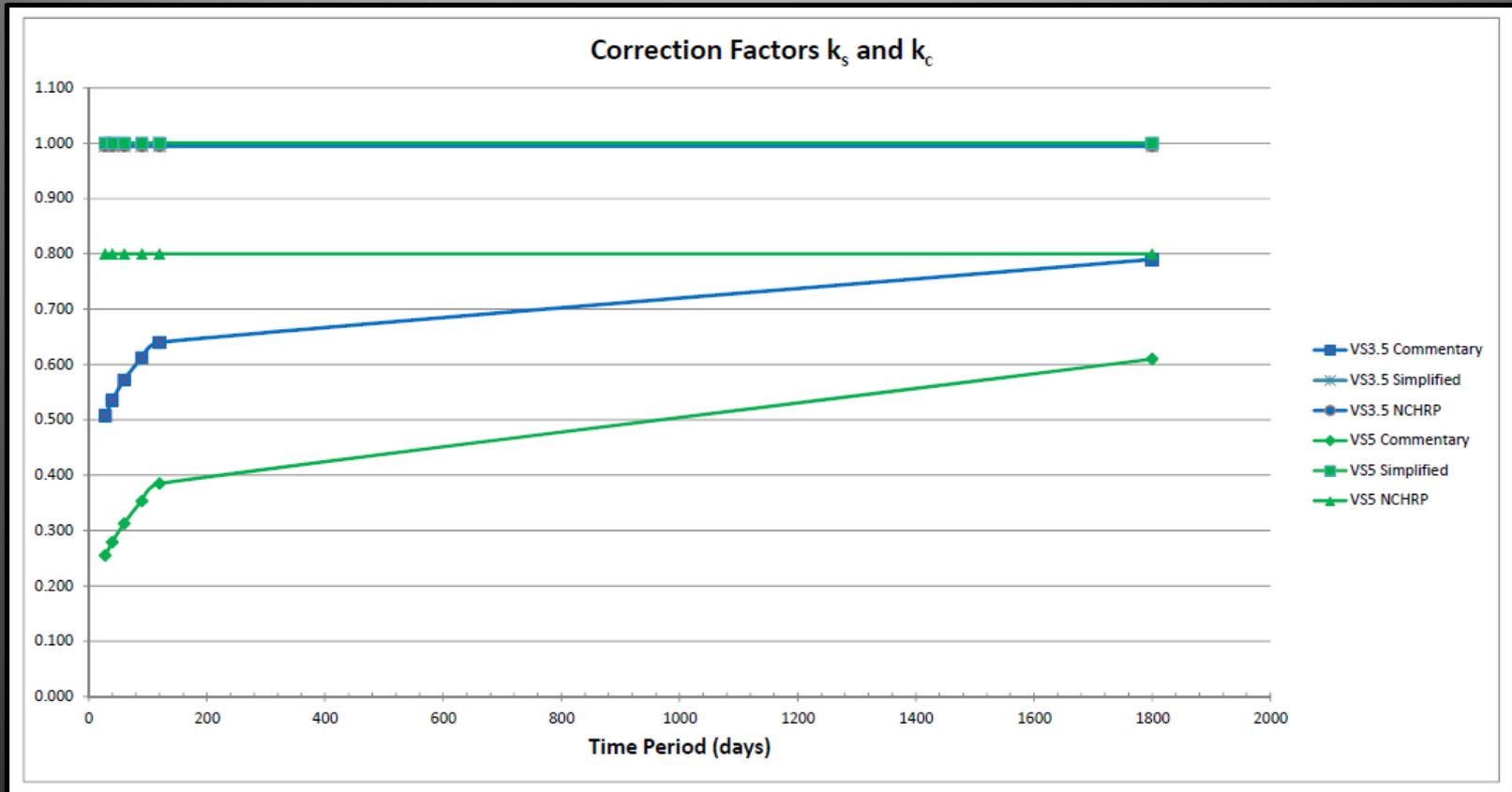
$$\epsilon_{sh} = k_s k_{hc} k_f k_{td} 0.48 \times 10^{-3} \quad (5.4.2.3.3-1)$$

For shrinkage:

$$k_s = \left[ \frac{\frac{t}{26e^{0.36(V/S)} + t}}{\frac{t}{45 + t}} \right] \left[ \frac{1064 - 94(V/S)}{923} \right] \quad (C5.4.2.3.2-2)$$



# V/S RATIO



$$k_s = 1.45 - 0.13(V/S) \geq 1.0$$

(5.4.2.3.2-2)

AASHTO LRFD, SIMPLIFIED

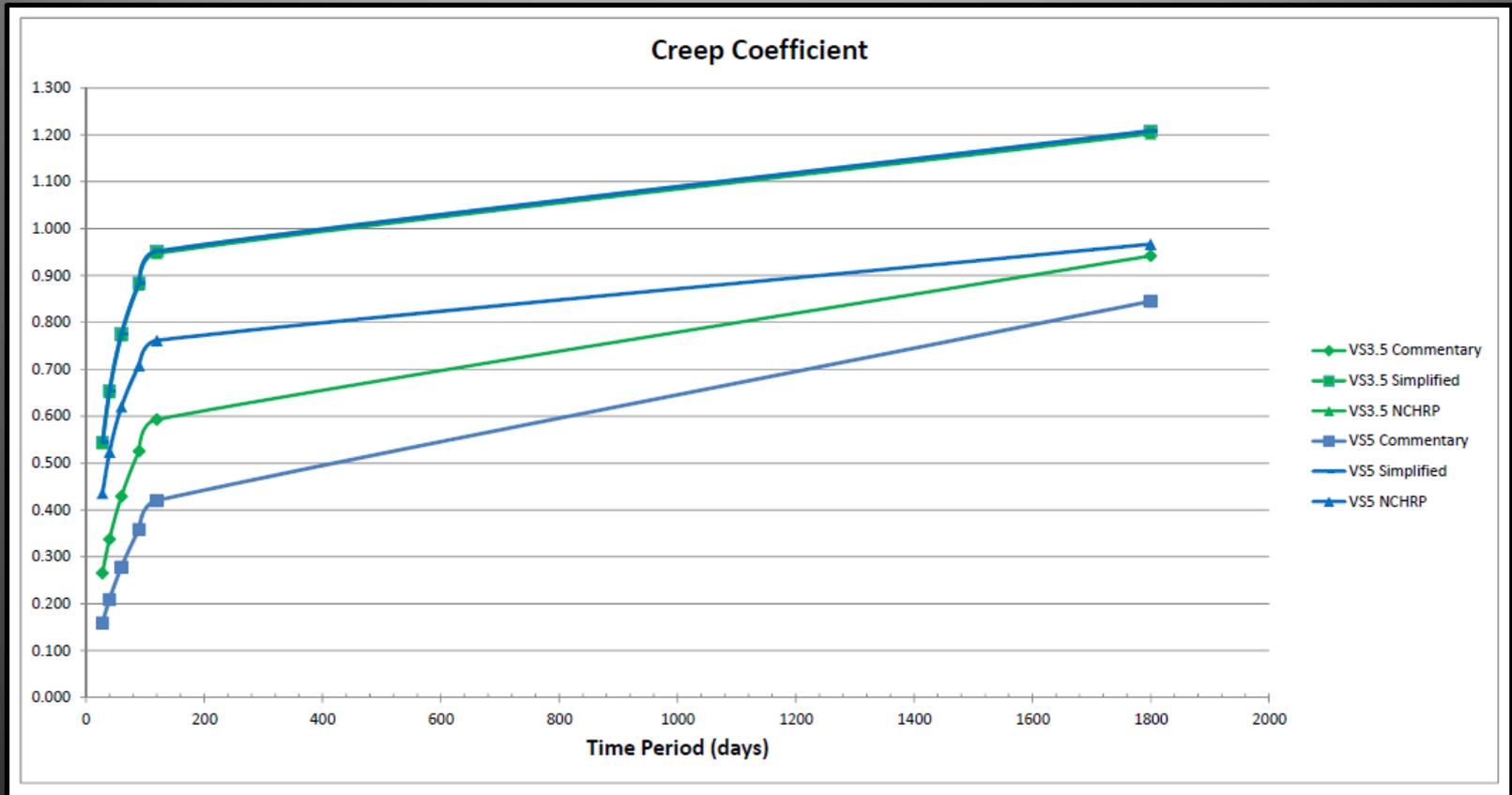
$$k_s = \frac{1064 - 94V/S}{735}$$

(51)

NCHRP 496 EQUATION

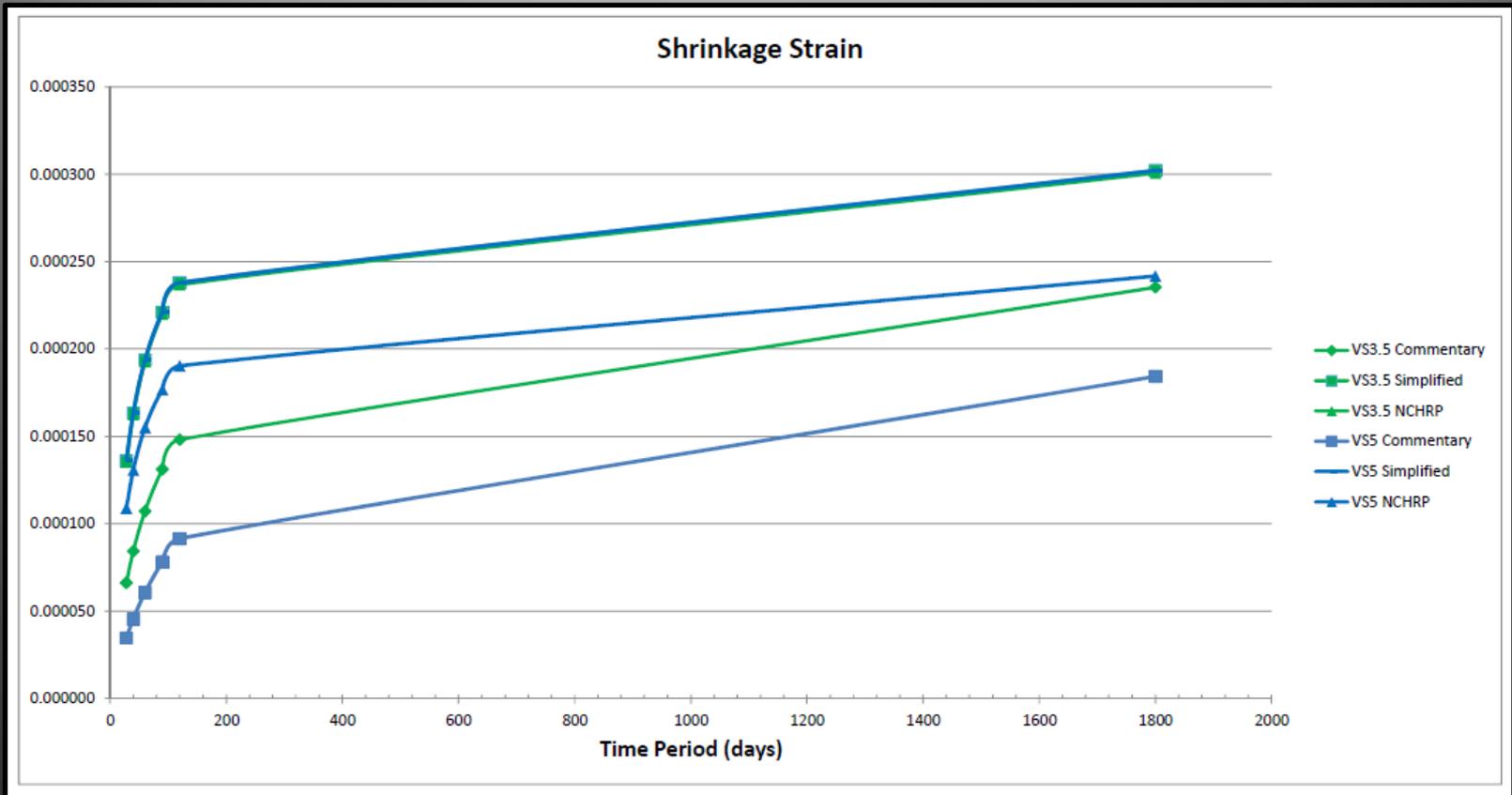


# CREEP COEFFICIENT





# SHRINKAGE STRAIN

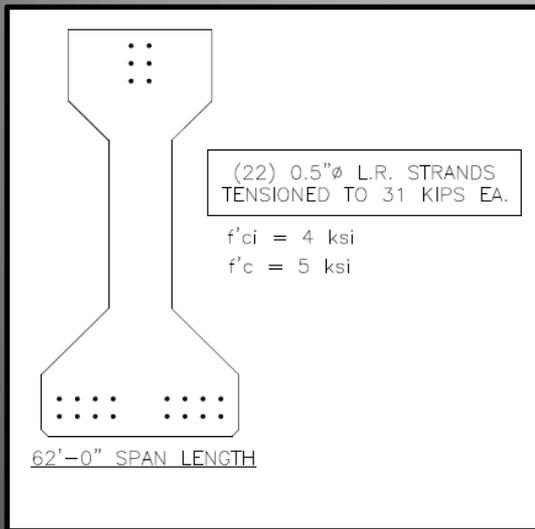


It is likely, however, that the full calculated force from deck shrinkage will not occur because of the presence of deck cracking and deck reinforcement. PCI recommends that in lieu of a more refined analysis, 50% of the deck shrinkage be applied.

**COMMENTARY EQUATION RESULTS ARE CONSISTENT WITH THIS STATEMENT**



# EXAMPLES:

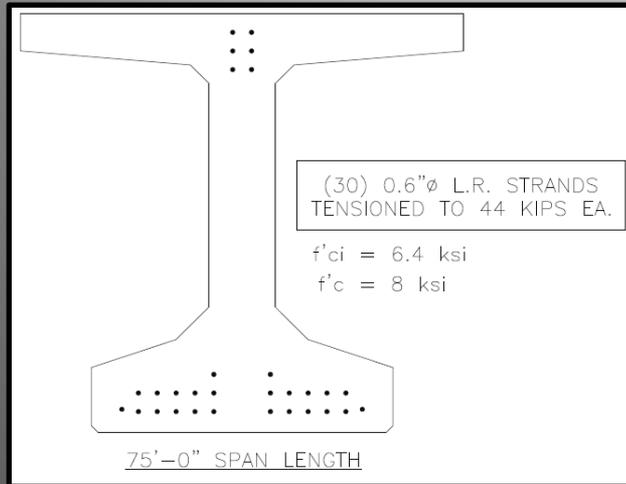


## Type III 8.5' Beam Spacing Restraint Moments

|        |                     | Continuity Made @ Days |            |            |            |             |
|--------|---------------------|------------------------|------------|------------|------------|-------------|
|        |                     | 28                     | 40         | 60         | 90         | 120         |
| 2 Span | Prestressed         | 1525                   | 1379       | 1186       | 977        | 829         |
|        | SW+Deck+SDL         | -524                   | -501       | -472       | -441       | -419        |
|        | Diff Deck Shrinkage | -335                   | -404       | -494       | -592       | -663        |
|        | <b>Total</b>        | <b>666</b>             | <b>474</b> | <b>220</b> | <b>-56</b> | <b>-253</b> |
| 3 Span | Prestressed         | 1220                   | 1103       | 948        | 781        | 663         |
|        | SW+Deck+SDL         | -420                   | -401       | -377       | -353       | -335        |
|        | Diff Deck Shrinkage | -268                   | -323       | -395       | -474       | -530        |
|        | <b>Total</b>        | <b>532</b>             | <b>380</b> | <b>176</b> | <b>-46</b> | <b>-201</b> |
| 4 Span | Prestressed         | 1307                   | 1182       | 1016       | 837        | 710         |
|        | SW+Deck+SDL         | -450                   | -430       | -405       | -378       | -359        |
|        | Diff Deck Shrinkage | -287                   | -346       | -423       | -507       | -568        |
|        | <b>Total</b>        | <b>570</b>             | <b>406</b> | <b>188</b> | <b>-48</b> | <b>-217</b> |



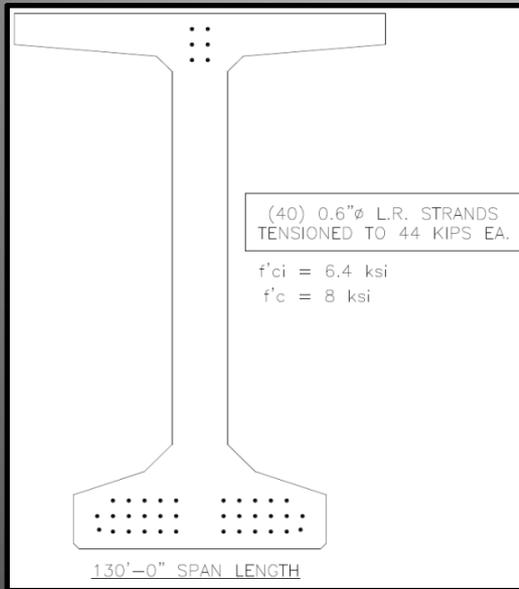
# EXAMPLES:



| PCBT 45<br>10.0' Beam Spacing<br>Restraint Moments |                     | Continuity Made @ Days |           |             |             |             |
|--|---------------------|------------------------|-----------|-------------|-------------|-------------|
|  |                     | 28                     | 40        | 60          | 90          | 120         |
| 2 Span   | Prestressed         | 1523                   | 1364      | 1160        | 948         | 800         |
|  | SW+Deck+SDL         | -648                   | -612      | -566        | -519        | -486        |
|  | Diff Deck Shrinkage | -690                   | -757      | -840        | -928        | -989        |
|  | <b>Total</b>        | <b>185</b>             | <b>-5</b> | <b>-246</b> | <b>-499</b> | <b>-675</b> |
| 3 Span   | Prestressed         | 1219                   | 1091      | 928         | 758         | 640         |
|  | SW+Deck+SDL         | -519                   | -489      | -453        | -415        | -388        |
|  | Diff Deck Shrinkage | -552                   | -605      | -672        | -742        | -791        |
|  | <b>Total</b>        | <b>148</b>             | <b>-3</b> | <b>-197</b> | <b>-399</b> | <b>-539</b> |
| 4 Span   | Prestressed         | 1305                   | 1168      | 994         | 812         | 686         |
|  | SW+Deck+SDL         | -555                   | -524      | -485        | -444        | -416        |
|  | Diff Deck Shrinkage | -591                   | -648      | -720        | -795        | -847        |
|  | <b>Total</b>        | <b>159</b>             | <b>-4</b> | <b>-211</b> | <b>-427</b> | <b>-577</b> |



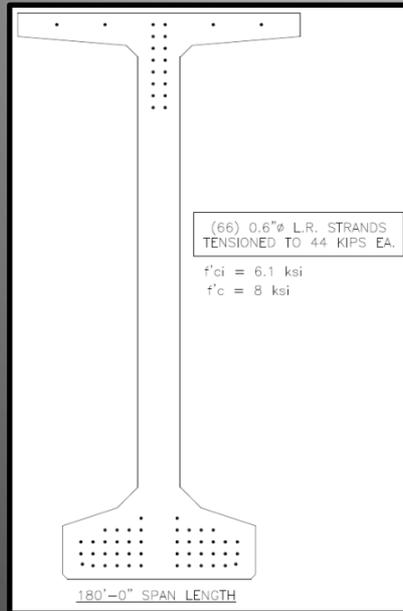
# EXAMPLES:



| PCBT 69<br>10.0' Beam Spacing<br>Restraint Moments |                     | Continuity Made @ Days |            |             |             |              |
|--|---------------------|------------------------|------------|-------------|-------------|--------------|
|  |                     | 28                     | 46         | 60          | 90          | 120          |
| 2 Span   | Prestressed         | 4013                   | 3402       | 3040        | 2474        | 2085         |
|  | SW+Deck+SDL         | -2197                  | -2018      | -1915       | -1752       | -1638        |
|  | Diff Deck Shrinkage | -1252                  | -1399      | -1485       | -1621       | -1716        |
|  | <b>Total</b>        | <b>564</b>             | <b>-16</b> | <b>-360</b> | <b>-899</b> | <b>-1270</b> |
| 3 Span   | Prestressed         | 3210                   | 2721       | 2432        | 1980        | 1668         |
|  | SW+Deck+SDL         | -1758                  | -1615      | -1532       | -1401       | -1311        |
|  | Diff Deck Shrinkage | -1002                  | -1119      | -1188       | -1297       | -1373        |
|  | <b>Total</b>        | <b>451</b>             | <b>-12</b> | <b>-288</b> | <b>-719</b> | <b>-1016</b> |
| 4 Span   | Prestressed         | 3438                   | 2914       | 2604        | 2120        | 1786         |
|  | SW+Deck+SDL         | -1882                  | -1729      | -1640       | -1501       | -1404        |
|  | Diff Deck Shrinkage | -1073                  | -1198      | -1273       | -1389       | -1470        |
|  | <b>Total</b>        | <b>483</b>             | <b>-13</b> | <b>-308</b> | <b>-770</b> | <b>-1088</b> |



# EXAMPLES:

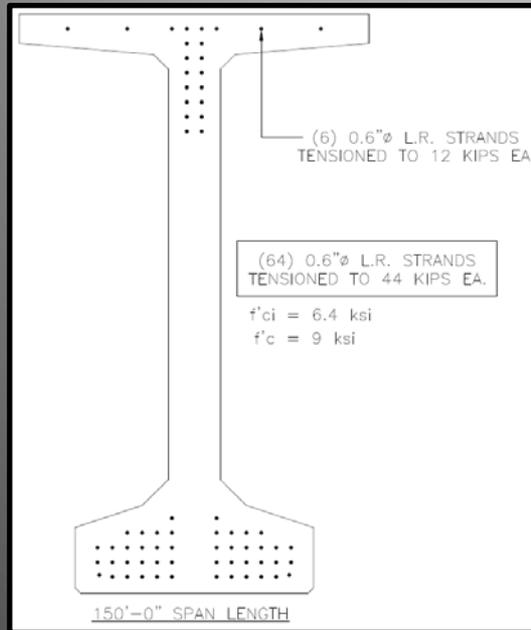


| PCEF 95.5<br>8.0' Beam Spacing<br>Restraint Moments |                     | Continuity Made @ Days |            |             |              |              |
|---|---------------------|------------------------|------------|-------------|--------------|--------------|
|   |                     | 28                     | 40         | 60          | 90           | 120          |
| 2 Span  | Prestressed         | 7235                   | 6596       | 5742        | 4803         | 4125         |
|   | SW+Deck+SDL         | -5046                  | -4756      | -4375       | -3955        | -3649        |
|   | Diff Deck Shrinkage | -1490                  | -1597      | -1738       | -1892        | -2003        |
|   | <b>Total</b>        | <b>698</b>             | <b>242</b> | <b>-370</b> | <b>-1043</b> | <b>-1527</b> |
| 3 Span  | Prestressed         | 5788                   | 5277       | 4594        | 3843         | 3300         |
|   | SW+Deck+SDL         | -4037                  | -3805      | -3500       | -3164        | -2919        |
|   | Diff Deck Shrinkage | -1192                  | -1278      | -1390       | -1513        | -1602        |
|   | <b>Total</b>        | <b>559</b>             | <b>194</b> | <b>-296</b> | <b>-835</b>  | <b>-1222</b> |
| 4 Span  | Prestressed         | 6198                   | 5651       | 4919        | 4115         | 3534         |
|   | SW+Deck+SDL         | -4323                  | -4075      | -3748       | -3388        | -3126        |
|   | Diff Deck Shrinkage | -1277                  | -1368      | -1489       | -1620        | -1716        |
|   | <b>Total</b>        | <b>598</b>             | <b>208</b> | <b>-317</b> | <b>-894</b>  | <b>-1308</b> |





# EXAMPLES:

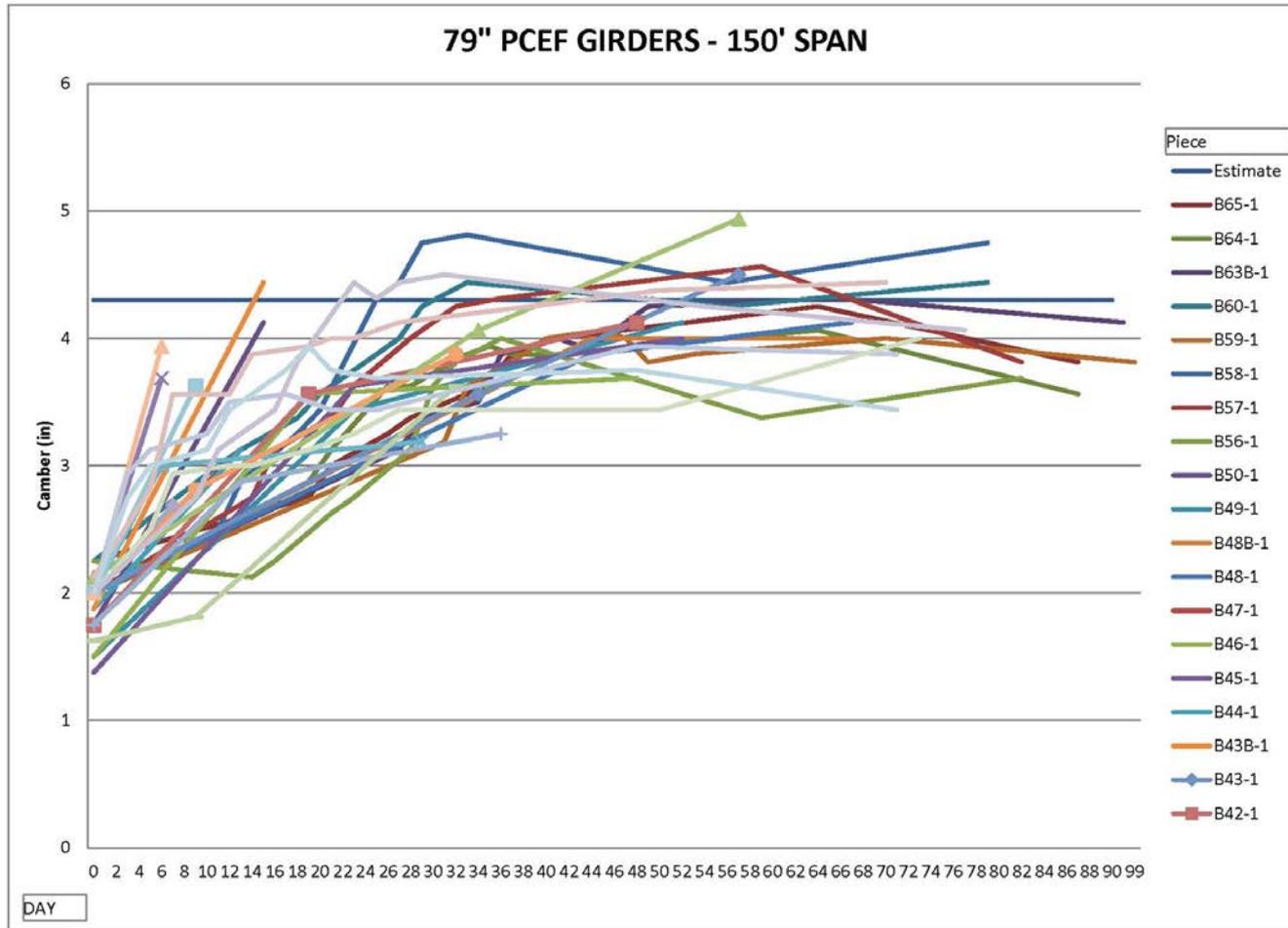


**PCBT 79**  
**9.25' Beam Spacing**  
**Restraint Moments**

|        |                     | Continuity Made @ Days |            |            |             |              |
|--------|---------------------|------------------------|------------|------------|-------------|--------------|
|        |                     | 28                     | 40         | 62         | 90          | 120          |
| 2 Span | Prestressed         | 5934                   | 5389       | 4609       | 3890        | 3331         |
|        | SW+Deck+SDL         | -3481                  | -3290      | -3021      | -2774       | -2581        |
|        | Diff Deck Shrinkage | -1333                  | -1445      | -1604      | -1751       | -1866        |
|        | <b>Total</b>        | <b>1120</b>            | <b>654</b> | <b>-16</b> | <b>-635</b> | <b>-1115</b> |
| 3 Span | Prestressed         | 4747                   | 4311       | 3687       | 3112        | 2665         |
|        | SW+Deck+SDL         | -2785                  | -2632      | -2417      | -2219       | -2064        |
|        | Diff Deck Shrinkage | -1066                  | -1156      | -1283      | -1401       | -1492        |
|        | <b>Total</b>        | <b>896</b>             | <b>524</b> | <b>-13</b> | <b>-508</b> | <b>-892</b>  |
| 4 Span | Prestressed         | 5083                   | 4617       | 3949       | 3333        | 2854         |
|        | SW+Deck+SDL         | -2982                  | -2818      | -2588      | -2377       | -2211        |
|        | Diff Deck Shrinkage | -1142                  | -1238      | -1374      | -1500       | -1598        |
|        | <b>Total</b>        | <b>960</b>             | <b>561</b> | <b>-14</b> | <b>-544</b> | <b>-955</b>  |

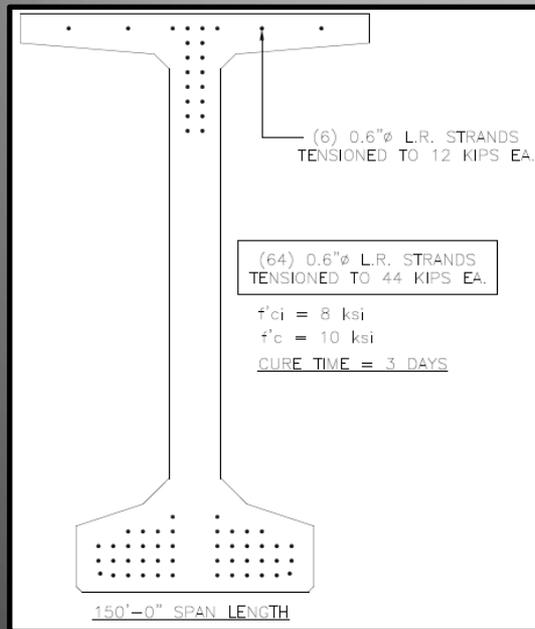


# MEASUREMENTS:





# CURE TO MATURITY:



The creep coefficient may be taken as:

$$\psi(t, t_i) = 1.9k_s k_{hc} k_f k_{td} t_i^{-0.118} \quad (5.4.2.3.2-1)$$

REDUCE COEFFICIENT TO < 1.0

- Increase  $t$  and  $f'_{ci}$

## PCEF 79 FULL CURE

9.25' Beam Spacing  
Restraint Moments

Continuity Made @ Days

|        |                     | 28          | 40          | 60           | 90           | 120          |
|--------|---------------------|-------------|-------------|--------------|--------------|--------------|
| 2 Span | Prestressed         | 4131        | 3720        | 3197         | 2643         | 2253         |
|        | SW+Deck+SDL         | -2794       | -2636       | -2439        | -2232        | -2085        |
|        | Diff Deck Shrinkage | -1589       | -1693       | -1824        | -1961        | -2059        |
|        | <b>Total</b>        | <b>-252</b> | <b>-609</b> | <b>-1066</b> | <b>-1550</b> | <b>-1891</b> |
| 3 Span | Prestressed         | 3305        | 2976        | 2558         | 2115         | 1803         |
|        | SW+Deck+SDL         | -2235       | -2109       | -1952        | -1786        | -1668        |
|        | Diff Deck Shrinkage | -1271       | -1354       | -1459        | -1569        | -1647        |
|        | <b>Total</b>        | <b>-202</b> | <b>-487</b> | <b>-853</b>  | <b>-1240</b> | <b>-1513</b> |
| 4 Span | Prestressed         | 3539        | 3187        | 2739         | 2265         | 1930         |
|        | SW+Deck+SDL         | -2394       | -2258       | -2090        | -1912        | -1786        |
|        | Diff Deck Shrinkage | -1361       | -1450       | -1562        | -1680        | -1764        |
|        | <b>Total</b>        | <b>-216</b> | <b>-521</b> | <b>-913</b>  | <b>-1328</b> | <b>-1620</b> |



## CONCLUSION:

- The 90 Day Clause of AASHTO LRFD may be relaxed for common PCBT span to depth ratios in solar radiation zone 3.
- Thermal + 50% LL + SDL for standard cases is already compressive and may be excluded in the determination of compression at the bottom flange/diaphragm interface
- Creep and Shrinkage using modern day concretes and the appropriate formulas allow continuity to be established at a younger age.
- If continuity needs to be established at a young age, increase release strength and cure time.



# QUESTIONS: