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INTRODUCTION

It is the intent of this chapter to establish the practices and specific requirements of the Structure and Bridge Division for the design and detailing of prestressed and post-tensioned concrete members. It will also provide design aids and other sources of information along with cross references to other Parts of this manual to assist in the design and preparation of plans.

References to AASHTO LRFD specifications in this chapter refer to the AASHTO LRFD Bridge Design Specifications including current VDOT Modifications (IIM-S&B-80).

The practices and specific requirements contained in this chapter have been established based on the Structure and Bridge Division’s experience, industry standards and recommendations, and technological advancements made over the years.

The practices and requirements set forth herein are intended to supplement or clarify the requirements of the AASHTO LRFD specifications, and to provide additional information to assist the designer. In the event of conflict(s) between the practices and requirements set forth herein and those contained in the AASHTO LRFD specifications, the more stringent requirements shall govern.

This chapter in the manual contains specific requirements and/or guidelines for the detailing of various prestressed and post-tensioned concrete components. It is not the intent of these requirements and guidelines to supersede the requirements contained in Chapter 1 of this manual but to convey necessary information to the designer for the detailing of prestressed and post-tensioned concrete components.

Prestressed concrete deck panels shall not be permitted for use as stay-in-place forms for steel and prestressed concrete girders/beams.

Standard sheets and cell libraries dealing with the details in this chapter can be found in other Parts of this manual as follows:

- Part 1 – Manual Overview and Use
- Part 3 – Current Details
- Part 4 – Prestressed Concrete Beam Standards
- Part 5 – Prestressed Concrete Adjacent Member Standards

It is expected that the users of this chapter will adhere to the practices and requirements stated herein.

Several major changes and/or additions to the past office practice (Part 2) are as follows:

1. Added camber at erection to camber computations and revised calculations and tolerances in bolster computations in Section 12.02.

2. Required design approval for concrete compressive strengths greater than 8,000 psi and up to 10,000 psi and added Design Requirement to Section 12.03.

3. Permitted debonded strand use only for prestressed concrete bulb-T beams.
Several major changes and/or additions to the past office practice (Part 2) are as follows (cont’d.):

4. Revised top flange sleeve material for deck drains to specify fiberglass reinforced epoxy pipe sleeves in place of galvanized steel.

5. Revised bridge layout points to line thru center of bearings/piles.

6. Update AASHTO LRFD specification article references to match 8th Edition locations.

NOTE:

Due to various restrictions on placing files in this manual onto the Internet, portions of the drawings shown do not necessarily reflect the correct line weights, line types, fonts, arrowheads, etc. Wherever discrepancies occur, the written text shall take precedence over any of the drawn view.
GENERAL INFORMATION:

This section specifies the general practices and requirements regarding the use of reinforcing steel for the design and fabrication of prestressed concrete members. For specific practices and requirements (sizes, spacings and misc. details), refer to the appropriate section of this chapter.

All prestressed and non-prestressed reinforcement used in the design and fabrication of prestressed concrete members shall conform to the requirements of Sections 223, 405 and 406 of the current edition of the VDOT Road and Bridge Specifications and as specified herein.

PRESTRESSED TENDONS:

Prestressed tendons shall conform to the requirements of Section 223 of the VDOT Road and Bridge Specifications and as specified below.

Prestressed tendons shall be uncoated, seven-wire, low-relaxation steel strands conforming to the requirements of ASTM A416 (AASHTO M203), Grade 270.

For strand properties and design strengths, see File No. 12.01-3.

The use of stress-relieved strands or substitution of stress-relieved strands for low-relaxation strands shall not be permitted.

See the individual sections of this chapter for the strand diameter for the prestressed concrete member to be used.

Strands for prestressed concrete members shall be distributed uniformly across the width of the member in a 2” x 2” grid pattern for strands up to and including 0.6” diameter. The grid pattern shall be laid out symmetrically about a vertical axis through the centroid of the member cross section.

For computation of prestress losses, see File Nos. 12.01-4 thru -6.

The use of debonded strands in prestressed members shall not be permitted.

Debonded strands may be used for prestressed Bulb-T beams but are not permitted for other prestressed concrete members. Debonded strands shall be designed in accordance with AASHTO LRFD Specifications.

NON-PRESTRESSED REINFORCEMENT:

Non-prestressed reinforcement shall conform to the requirements of Sections 405 and 406 of the VDOT Road and Bridge Specifications and as specified below.

Deformed reinforcing bars shall conform to the requirements of ASTM A615, Grade 60.

Plain steel bars when used as dowels shall conform to the requirements of ASTM A36.

Spiral wire ties shall conform to the requirements of ASTM A82 (AASHTO M32).
NON-PRESTRESSED CORROSION RESISTANT REINFORCEMENT:

In accordance with current IIM-S&B-81, non-prestressed reinforcement in prestressed concrete members shall be corrosion resistant reinforcing (CRR) steel bars as follows:

- For prestressed concrete bulb-T and AASHTO beams, stirrups and other reinforcement extending into the concrete deck slab; continuity reinforcement (Class as listed in current IIM-S&B-81).
- For prestressed concrete voided slabs and box beams, all reinforcement except strands (Class as listed in current IIM-S&B-81).

POST-TENSIONED TENDONS:

Post-tensioning (using ducts and grouting) shall not be used without a design waiver approved by the State Structure and Bridge Engineer. Exempt are prestressed concrete voided slabs with transverse ties or prestressed concrete box beams with transverse ties. See File Nos. 12.05-2 and 12.06-3 for transverse post-tensioning for voided slabs and box beams respectively.
**SEVEN-WIRE GRADE 270 LOW-RELAXATION STRANDS**

<table>
<thead>
<tr>
<th>Nominal Diameter of Strand (in)</th>
<th>Nominal Area of Strand ($A_{ps}$ (in$^2$))</th>
<th>Ultimate Strength of Strand ($f_{pu} \times A_{ps}$ (lbs))</th>
<th>Yield Strength of Strand ($f_{py} \times A_{ps}$ (lbs))</th>
<th>Maximum Jacking Force ($F_{pj}$ (lbs))</th>
<th>Required Tension Force Immediately Prior to Release ($F_{pbt}$ (lbs))</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 (0.375)</td>
<td>0.085</td>
<td>22950</td>
<td>20660</td>
<td>18590</td>
<td>17210</td>
</tr>
<tr>
<td>7/16 (0.438)</td>
<td>0.115</td>
<td>31050</td>
<td>27950</td>
<td>25160</td>
<td>23290</td>
</tr>
<tr>
<td>1/2 (0.500)</td>
<td>0.153</td>
<td>41310</td>
<td>37180</td>
<td>33460</td>
<td>30980</td>
</tr>
<tr>
<td>1/2 (special)</td>
<td>0.167</td>
<td>45000</td>
<td>40500</td>
<td>36450</td>
<td>33750</td>
</tr>
<tr>
<td>0.60</td>
<td>0.217</td>
<td>58590</td>
<td>52730</td>
<td>47460</td>
<td>43940</td>
</tr>
</tbody>
</table>

$f_{pu}$ = specified tensile strength of prestressing steel (psi).

$f_{py} = 0.90 \times f_{pu}$ = yield stress of prestressing steel (AASHTO LRFD 5.4.4.1).

$F_{pj} = 0.90 \times f_{py} \times A_{ps}$ = maximum tensioning force (jacking force) per strand for short periods of time prior to seating to offset losses due to anchorage set and other factors (AASHTO LRFD Construction Specifications).

$F_{pbt} = 0.75 \times f_{pu} \times A_{ps}$ = required tensioning force per strand immediately prior to release (after loss due to anchorage set and other factors). This force shall be entered in the table on the standard beam detail sheet as the "Prestress force at Release" (AASHTO LRFD 5.9.2.2).
PRESTRESS LOSSES:

The loss of prestress can be defined as the difference between the initial stress in the strands and the effective stress in the strands after losses have occurred. The loss of prestress can generally be attributed to the cumulative effects from the following sources:

- Elastic Shortening ($\Delta f_{pES}$)
- Relaxation of Prestressing Steel ($\Delta f_{pR}$)
- Shrinkage of Concrete ($\Delta f_{pSR}$)
- Creep of Concrete ($\Delta f_{PCR}$)
- Anchorage Set (seating or slip) caused by movement of strands due to chuck seating in wedge-type anchorages
- Other Factors such as casting bed and form deformations, and temperature effects, if any.

Producers of prestressed concrete members will normally make the necessary adjustments to the prestressing (jacking) force to compensate for the losses due to anchorage set and other factors.

COMPUTATION OF PRESTRESS LOSSES:

Prestress losses, excluding losses due to friction for normal designs, shall be computed in accordance with the requirements contained in Article 5.9.3 of the AASHTO LRFD specifications as supplemented herein.

For the design of prestressed concrete members, prestress losses excluding friction shall be computed at the following stages in the life of the member:

Transfer (release) of Prestress

$$\Delta f_s (at\ transfer) = \Delta f_{pES}$$

For estimating elastic shortening loss ($\Delta f_{pES}$) to be used in the above equation and the equation below for $\Delta f_s$ (at service), Article 5.9.3.2.3a of the AASHTO LRFD specifications gives the following alternate equation:

$$\Delta f_{pES} = A_{ps} \times f_{pbt} \times \left( I_g + e_m^2 \times A_g \right) - e_m \times M_g \times A_g$$

$$A_{ps} \times \left( I_g + e_m^2 \times A_g \right) + \frac{A_g \times I_g \times E_{ci}}{E_p}$$

AASHTO LRFD Eq. C5.9.3.2.3a-1

where

- $E_p$ = modulus of elasticity of prestressing steel
  = 28,500 ksi

- $A_{ps}$ = area of prestressing steel (in$^2$)

- $A_g$ = gross area of section (in$^2$)
f'_{ci} = \text{strength of concrete at release (ksi)}

w_c = \text{unit weight of concrete (kcf)}

E_{ci} = \text{modulus of elasticity of concrete at release after losses (ksi)}
\quad = 33,000 \times w_c^{3/2} \times \sqrt{f'_{ci}}

e_m = \text{average prestressing steel eccentricity at midspan (in\(^2\))}

f_{pbt} = \text{stress in prestressing steel immediately prior to transfer (ksi)}
\quad = 0.75 \times f_{pu}

I_g = \text{moment of inertia of the gross concrete section (in}^4\text{)}

M_g = \text{midspan moment due to member self-weight (kip-in)}

\text{Service Load}

\Delta f_s (\text{at service}) = \Delta f_{pT} = \Delta f_{pES} + \Delta f_{pLT} \quad \text{AASHTO LRFD Eq. 5.9.3.1-1}

\text{where } \Delta f_s (\text{at service}) = \Delta f_{pT} = \text{total loss excluding friction (ksi)}

\Delta f_{pES} = \text{loss due to elastic shortening (ksi)}

\Delta f_{pLT} = \text{losses due to long – term shrinkage and creep of concrete, and relaxation of steel (ksi)}

\text{For estimating the time dependent prestress losses (} \Delta f_{pLT} \text{) to be used in the above equation for } \Delta f_s (\text{at service}), \text{Article 5.9.3.3 of the AASHTO LRFD specifications gives the following lump sum loss equation:}

\Delta f_{pLT} = 10.0 \times \frac{f_{pl} \times A_{ps}}{A_g} \times \gamma_h \times \gamma_{st} + 12.0 \times \gamma_h \times \gamma_{st} + \Delta f_{pR} \quad \text{AASHTO LRFD Eq. 5.9.3.3-1}

\text{where } \Delta f_{pLT} = \text{time dependent loss due to creep and shrinkage of concrete, and relaxation of steel}

A_g = \text{gross area of section (in}^2\text{)}

A_{ps} = \text{area of prestressing steel (in}^2\text{)}

\gamma_h = 1.7 - 0.01 \times H = \text{correction factor relative humidity of the ambient air}

H = \text{the average annual ambient relative humidity (%)}
\quad = 70
\[ \gamma_{st} = \frac{5}{1 + f_c} \] = correction factor for specified concrete strength at time of prestress transfer to the concrete member

\[ f_{pl} = \text{prestressing steel stress immediately prior to transfer (ksi)} \]
\[ = 0.75f_{pu} \]

\[ \Delta f_{pR} = \text{an estimate of relaxation loss (ksi)} \]
\[ = 2.4 \text{ ksi for low relaxation strand} \]

The gains due to elastic deformations at time of transfer shall not be added to the time dependent losses to determine the Total Loss of Prestress, \( \Delta f_s \) (at service). Users of the Conspan Rating program must remove these gains from the Total Loss of Prestress, \( \Delta f_s \) (at service), generated by the program and manually input the total loss at service.

For unusual or complex designs where a more accurate determination of time dependent losses is required, the refined estimate for time dependent prestress losses contained in Article 5.9.3.4 of the AASHTO LRFD specifications shall be used.
DRAPING OF STRANDS:

Prestressed members shall be designed with strands having either a straight or a double draped (harped) profile along the length of the member.

Draped points (hold-downs) shall be located at 0.4L and 0.6L where L is the bearing centerline to bearing centerline distance.

The number of draped strands permitted shall not exceed 14 (7 rows of 2 strands).

COMPUTATION OF HOLD-DOWN FORCES:

Strand hold-down devices are rated (maximum safe working load) by uplift force per strand as well as by total uplift force per device. The magnitude of these forces shall be investigated and shall not exceed the maximum safe working load criteria found on the following sheet.

Definitions:

\[ F_{pull} = \] Maximum pretensioned force (jacking force) per strand immediately prior to transfer

\[ F_v = \] Uplift force per strand at drape point

\[ F_h = \] Horizontal force per strand at drape point

\[ V = \] Vertical draped distance for individual strand between midspan and beam end positions

\[ H = \] Horizontal distance from end of beam to drape point

Friction Factor = Increase in force due to friction losses (1.05 for swivel devices and 1.15 for non-swivel devices)

Equations for calculating hold-down forces:

\[ F_{pull} = 0.80 \times f_{pu} \times A_{ps} \] (for low-relaxation strands)

\[ F_v = F_{pull} \times \left( \frac{V}{H} \right) \times \text{Friction Factor} \]

Total Uplift Force = \( \Sigma F_v \)
Hold-down limits for uplift force per strand as well as by total uplift force per device:

For 6 draped strands (3 rows of 2 strands) or less:

\[ F_v \leq 6.0 \text{ kips per strand for swivel devices} \]
\[ \leq 6.5 \text{ kips per strand for non-swivel devices} \]

Total Uplift Force = \leq 40 \text{ kips per device}

For 8 draped strands (4 rows of 2 strands):

\[ F_v \leq 5.0 \text{ kips preferred per strand for swivel devices (5.5 kips maximum)} \]
\[ \leq 5.5 \text{ kips preferred per strand for non-swivel devices (6.0 kips maximum)} \]

Total Uplift Force = \leq 40 \text{ kips preferred per device (48 kips maximum per device)}

For 10 draped strands (5 rows of 2 strands):

\[ F_v \leq 4.8 \text{ kips per strand for swivel devices} \]
\[ \leq 4.8 \text{ kips per strand for non-swivel devices} \]

Where maximum force per strand can be met for swivel devices, but not for non-swivel devices, prohibit non-swivel devices on Prestressed Concrete Bulb-T standard sheet.

Total Uplift Force = \leq 40 \text{ kips preferred per device (48 kips maximum per device)}

Where Total Uplift Force > 48 kips, two devices will be required. Use 12 strand criteria.

For 12 draped strands (assumed 3 rows of 2 strands per device): Two devices physically required per location

\[ F_v \leq 6.0 \text{ kips per strand for swivel devices} \]
\[ \leq 6.5 \text{ kips per strand for non-swivel devices} \]

Total Uplift Force = \leq 40 \text{ kips per device}

For 14 draped strands (assumed 4 rows of 2 strands at one device; 3 rows at other): Two devices physically required per location

\[ F_v \leq 5.0 \text{ kips preferred per strand for swivel devices (5.5 kips maximum)} \]
\[ \leq 5.5 \text{ kips preferred per strand for non-swivel devices (6.0 maximum)} \]

Total Uplift Force = \leq 40 \text{ kips preferred per device (48 kips maximum per device)}

Hold-down devices with a maximum safe working load of 48 kips per unit will increase cost. Designers shall investigate means to reduce the total uplift force to 40 kips per device prior to finalizing designs requiring a 48-kip device. For example and additional discussion, see design parameter influence on hold-down forces on the following sheet.
Where number of strands results in a total uplift force in excess of 48 kips, the force must be split into two locations straddling the 0.4L and 0.6L points. Number of draped strands exceeding 10 will physically require split locations regardless of total uplift force.

**Design Parameter influence on hold-down forces:**

Reducing beam depth by increasing concrete strength can reduce hold-down forces per strand and per device. As example, consider the following:

Constants: Simple span length = 109’ (total beam length = 111’), beam spacing = 10’ and distance between top draped strand and top of top flange = 4” (to clear BL0501 position and clear inserts for this particular case), $f_{ci} = 0.75f_c$ used; forces reported for swivel device in all cases shown below.

For $f_c = 6$ ksi using PCBT77 with 6 draped strands (30 strands total):

<table>
<thead>
<tr>
<th>$F_v$</th>
<th>Total Uplift Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.14 kips</td>
<td>36.8 kips</td>
</tr>
</tbody>
</table>

For $f_c = 8$ ksi using PCBT61 with 6 draped strands (38 stands total):

<table>
<thead>
<tr>
<th>$F_v$</th>
<th>Total Uplift Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.67 kips</td>
<td>28.0 kips</td>
</tr>
</tbody>
</table>

For $f_c = 10$ ksi using PCBT53 with 6 draped strands (44 strands total):

<table>
<thead>
<tr>
<th>$F_v$</th>
<th>Total Uplift Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.75 kips</td>
<td>22.5 kips</td>
</tr>
</tbody>
</table>

Note that the hold-down force per strand can be reduced by draping additional strands as “V” is reduced per strand. However, the total hold-down force will increase and draping more strands to reduce the force per strand may be inefficient.

The top draped strands are typically placed immediately below the top transverse mild reinforcement at beam ends. Partial draping of strands [i.e., top draped strand located more than approximately 4” (shallower beam) to 8” (deeper beam) below top of beam at end of beam] to reduce hold-down forces is not recommended. The pretensioned anchorage zone design tables in File Nos. 12.12-5 thru -8 were derived using fully draped strands. Designers should conduct an analysis with the full strut-and-tie based model where harped strands are partially draped at the end of the girder to determine anchorage zone reinforcement needs.
DEFINITIONS:

C = Net expected camber in the beam at release of strands

C_{er} = Design camber at erection (using PCI multipliers)

\Delta_{bm} = Deflection of beam from its own weight

\Delta_{c1} = Deflection of beam from dead load weight of deck slab, bolster, diaphragms and construction tolerance

\Delta_{c2} = Deflection of composite section from dead load, e.g. parapet, rail and curb, added after deck slab is cast

\Delta_{c} = Deflection of composite section from total dead load

\Delta_{st} = Camber due to prestress force at release

CT = Camber tolerance

TOLERANCE LIMITS:

From Section 405 of the VDOT Road and Bridge Specifications:

Camber tolerance = +0.3(C_{er}) to \frac{-1}{2} C_{er}

Beam depth (overall) tolerance = \pm \frac{1}{4} "

CAMBER CALCULATIONS:

1. Camber due to prestress force at release:

![Diagram of camber calculation]
\[ \Delta_{st}(\uparrow) = \frac{P_{si}}{E_{ci} \times I_g} \times \left[ \frac{e_s \times L^2}{8} - \frac{e' \times a^2}{6} \right] \]

for LRFD:

- \( f'_{ci} \) = strength of concrete at release (ksi)
- \( I_g \) = moment of inertia of the gross concrete section (in\(^4\))
- \( E_{ci} \) = modulus of elasticity at release (ksi)
- \( w_c \) = unit weight of concrete (kcf)
- \( f_{pu} \) = specified tensile strength of prestressing steel (ksi)
- \( P_{si} \) = \( 0.75 \times A_{ps} \times f_{pu} \times (1.0 - \text{loss at release}) \) (kips)
- \( A_{ps} \) = area of prestressing steel (in\(^2\))
- \( e_s \) = eccentricity of prestressing strand at midspan (in)
- \( e' \) = difference between eccentricity of prestressing strand at midspan and at end of the beam (in)
- \( L \) = total beam length (in)
- \( a \) = distance between harp point and end of beam (in)

2. Deflection of beam from its own weight:

\[ \Delta_{bm}(\downarrow) = \frac{5 \times w \times L^4}{384 \times E_{ci} \times I_g} \]

where \( w \) = dead load weight of beam (kips/in)

3. Net camber at release:

\[ C = \Delta_{st}(\uparrow) + \Delta_{bm}(\downarrow) \]

4. Design camber at erection (using PCI multipliers):

\[ C_{er} = 1.8 \times \Delta_{st}(\uparrow) + 1.85 \times \Delta_{bm}(\downarrow) \]
DEFINITIONS:

B = Minimum thickness of bolster over centerline of beam at supports (thickness at intersection of centerline of beam and centerline of bearing).

$\Delta c_1$ = Deflection of beam from dead load weight of deck slab, bolster, diaphragms and construction tolerance

CT = Camber tolerance = 0.3 x $C_{er}$ (for purpose of bolster calculation)

$\sum D$ = Beam depth tolerance + $C_{er}$ + CT + (cross slope x $^{1/2}$ top flange width) + (cross slope x horizontal curve ordinate) + $^{1/2}$

MINIMUM BOLSTER CALCULATIONS:

For straight gradient:

\[ B \geq \sum D - \Delta c_1 \] (but not less than 1")

For sag vertical curve:

\[ B \geq \sum D + V.C. \text{ ordinate} - \Delta c_1 \] (but not less than 1")

For hump vertical curve:

\[ B \geq \sum D - \Delta c_1 \] (but not less than 1")

Where “arriving” and “departing” beams result in calculated differences (less than $^{1/4}$") in pier seat elevations, add the difference to the minimum bolster thickness computed above.
1. Plans having prestressed concrete members shall include a dead load deflection diagram. The diagram shown above is for a straight gradient. Show appropriate gradient (straight, hump or sag) shape on the dead load deflection diagram.

2. For full integral abutments, revise note reading $\ell$ of bearing shown above to read $\ell$ of integral abutment.

3. In the deflection diagram show deflections using $\frac{1}{8}$" increments.

4. Bridge seat elevations shall be set so as to maintain minimum design slab thickness at any point over the beam, taking into account beam tolerances and camber due to prestressing.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Beam & At $a$ & At $b$ \\
\hline
$\Delta C_1$ & $\Delta C_2$ & $\Delta C_1$ & $\Delta C_2$ \\
\hline
\end{tabular}
\end{table}

\textbf{DEAD LOAD DEFLECTION DIAGRAM}

\textbf{ANTICIPATED DEAD LOAD DEFLECTION}

\section*{References}

1. Plans having prestressed concrete members shall include a dead load deflection diagram. The diagram shown above is for a straight gradient. Show appropriate gradient (straight, hump or sag) shape on the dead load deflection diagram.

2. For full integral abutments, revise note reading $\ell$ of bearing shown above to read $\ell$ of integral abutment.

3. In the deflection diagram show deflections using $\frac{1}{8}$" increments.

4. Bridge seat elevations shall be set so as to maintain minimum design slab thickness at any point over the beam, taking into account beam tolerances and camber due to prestressing.
1. Plans having prestressed concrete members shall include a table with top of slab elevations at the following points along centerline of beam(s).

- spans < 100 feet, use $1/4$ points
- spans $\geq$ 100 feet, use $1/10$ points

2. For full integral abutments, revise note reading Face of backwall at abutment or $\mathbb{C}$ pier shown above on left side of the plan detail to read End of slab at integral abutment or $\mathbb{C}$ of pier. Revise note reading $\mathbb{C}$ bearing shown above on left side of the plan detail to read $\mathbb{C}$ of integral abutment.

3. For semi-integral abutments, revise note reading Face of backwall at abutment or $\mathbb{C}$ pier shown above to read Face of integral backwall or $\mathbb{C}$ pier.
PRESTRESSED CONCRETE BULB-T SECTIONS:

The prestressed concrete Bulb-T sections (PCBT-series) adopted by the Structure and Bridge Division were developed by the Prestressed Concrete Committee for Economical Fabrication (PCEF), a joint committee of FHWA bridge engineers, mid-Atlantic State DOT engineers and precast, prestressed concrete suppliers.

For Prestressed Concrete Bulb-T Preliminary Design Charts, see File Nos. 12.03-6 thru -10.

BEAM SPACING:

The maximum beam/girder spacing shall be 12'-0" unless a design waiver is approved. For splayed (variable spaced beams), the maximum spacing is applied at mid-span, but the spacing at the widest splayed end shall not exceed 14'-0".

The deck slab overhang (distance from the centerline of the exterior beam to the edge of the deck) for the exterior beam is dependent on these factors:

1. 0.3 x beam spacing.
2. For overhangs exceeding 0.3 x beam spacing, a yield-line analysis is required.
3. If the exterior beam controls the design, reduce the deck slab overhang to the point that the interior and exterior beam design is nearly equal.
4. Check the space required for deck drains for conflicts with the location of the exterior beam lines.
5. Aesthetic considerations.

The minimum deck overhang shall be 3" beyond the edge of the flange. The maximum deck overhang shall be 0.35 x the beam/girder spacing or 4'-0", whichever is less including where straight beams are used on a curved alignment. Deck overhang and bridge railing/parapet geometry shall meet the layout requirements on File No. 10.01-6.

NUMBER OF BEAMS:

Because of concerns for redundancy, new bridges shall have a minimum of four beams per span with the following exceptions:

- One lane bridges on low-volume (ADT < 400) roads where a minimum of three beams may be used;
- Typically, pedestrian bridges use two-beam systems and are fracture critical structures.
CONCRETE:
Concrete used in the design of prestressed concrete Bulb-T’s shall be Class A5 having a minimum 28 day compressive strength of 5000 psi. Concrete having strengths up to 8,000 psi may be used whenever it is economical or necessary to meet the design requirements of the project. Concrete strengths greater than 8,000 psi and up to 10,000 psi may only be used with design approval (see Design Requirements on next sheet for rationale). Concrete strengths exceeding 10,000 psi may be used only after obtaining a design waiver.

The minimum compressive strength of concrete required at release shall not exceed 0.8 f’c and shall be specified as 0.8 f’c in the General Notes shown on the title sheet of the plans even where a lesser value may be acceptable per design. Lower minimum compressive strength at release will increase the expected camber.

REINFORCEMENT:
All prestressed and non-prestressed reinforcement used in the design and fabrication of prestressed concrete Bulb-T’s shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

Prestressed concrete Bulb-T’s shall normally be designed using 0.6” diameter strands. For draping of strands and hold-down forces, see File Nos. 12.01-7 thru -9.

COMPOSITE SECTION PROPERTIES AND INTERFACE SHEAR REINFORCEMENT:
In computing the composite section properties for prestressed concrete Bulb-T’s, the effect of bolster shall be neglected.

For composite prestressed construction where slabs are assumed to act integrally with the prestressed concrete Bulb-T, the effective flange width shall be computed in accordance with the requirements of Article 4.6.2.6 of the AASHTO LRFD specifications.

Interface shear reinforcement in standards shall extend at least 2 inches above the plane of the bottom of the deck slab and 3" below the plane of the top of the deck slab. Where projecting the interface shear reinforcement to the mid-depth of the deck slab will not meet the above criteria due to camber and tolerances, modify the standard details for a varying bar projection or an additional bar callout/length.
DESIGN REQUIREMENTS:

Minimum depth sections utilizing high concrete strengths and a large number of strands (e.g., > 40 strands for most sections) are not encouraged to achieve longer spans where vertical clearance or hydraulic opening is not a controlling factor. Utilizing higher strength concrete with larger number of strands increases camber and the required bolster height which can cause fabrication and construction complexities.

Where minimum depth sections utilizing high concrete strengths and a large number of strands would be necessary where vertical clearance or hydraulic opening is a limiting factor, changes to the vertical profile should be considered during project scoping.

Designs where dead load deflection exceeds camber are prohibited.

MEMBER WEIGHT AND LENGTH LIMITATIONS:

When considering a prestressed concrete Bulb-T section to use, the designer shall investigate the feasibility of having the member hauled to the project site and erected.

BEAM END DETAILS FOR INTEGRAL ABUTMENTS:

For beam end details for integral abutments, see File Nos. 17.03-26 thru -29.

The designer shall locate 1 1/2" diameter open holes to ensure there are no conflicts with prestressing strands. In the event this is not possible, the designer may consider the option of relocating the draped strands providing the beam stresses do not exceed the allowable. When relocating draped strands, the designer may increase the vertical spacing of strands but shall maintain 2" increments between rows of draped strands.

Modify the end of the beam shown in the Part Plan and Part Elevation shown on the prestressed concrete beam standard sheet to show the location of the 1 1/2" diameter open holes in the beam web. For semi-integral abutments for bridges on skews, modify the Part Plan to show the top flange clip or beam end bevel.

MISCELLANEOUS BEAM DETAILS:

For camber and bolster computations, dead load deflection diagrams and top of slab elevations along centerline beams, see File Nos. 12.02-1 thru -5.

For beam diaphragm details, see File Nos. 12.10-1 thru -9. For beam continuity diaphragm details, see File Nos. 12.11-1 thru -10. For pretensioned anchorage zone design tables and reinforcement details, see File Nos. 12.12-1 thru -8.
TOP FLANGE SLEEVE DETAILS FOR DECK DRAINS:

When top flanges of Bulb-T sections interfere with the installation of bridge deck drain pipes, a fiberglass reinforced epoxy pipe sleeve shall be provided and located within the limits shown below.

When the location of deck drain pipe will not provide the minimum distance from edge of top flange to pipe sleeve shown above, the designer shall either decrease the length of deck cantilever or locate the deck drain pipe outside the top flange.

For plans with deck drains where top flange sleeves are required, details of the pipe sleeve shall be provided on the miscellaneous beam detail sheet.

Cost for furnishing and installing pipe sleeves shall be included in the contract unit price for prestressed concrete members.
Maximum number of strands in row number 1: 14
   2: 14
   3: 12
   4: 6
   5 and higher: 2

<table>
<thead>
<tr>
<th>Beam Designation</th>
<th>Depth D (in)</th>
<th>Area A (in²)</th>
<th>Volume to Surface Ratio V/S</th>
<th>Centroid to Bottom yb (in)</th>
<th>Moment of Inertia I (x 10³ in⁴)</th>
<th>Section Modulus S_top (in³)</th>
<th>S_bott (in³)</th>
<th>Weight @ 150 pcf (lbs/liv. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCBT-29</td>
<td>29</td>
<td>634.7</td>
<td>3.40</td>
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<td>3.42</td>
<td>29.92</td>
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<td>14810</td>
<td>894</td>
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<td>914.7</td>
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<td>601.3</td>
<td>17078</td>
<td>17795</td>
<td>953</td>
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<td>PCBT-77</td>
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<td>970.7</td>
<td>3.43</td>
<td>37.67</td>
<td>788.7</td>
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<td>20937</td>
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<td>PCBT-85</td>
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<td>1258.5</td>
<td>26484</td>
<td>27672</td>
<td>1128</td>
</tr>
</tbody>
</table>
PRELIMINARY DESIGN CHART PARAMETERS:

The PCBT Preliminary Design Charts are intended to assist the designer in selecting the most economical bulb-T section for a particular beam spacing and span length. The preliminary chart is not intended to provide a final beam design.

The PCBT Preliminary Design Charts were developed in accordance with the AASHTO LRFD 7th Edition Specifications and VDOT Structure and Bridge IIM-S&B-80.5 VDOT Modifications to the AASHTO LRFD 7th Edition, using LEAP Bridge Enterprise – ConSpan Version 14.00.00.19.

Design parameters used for the development of the preliminary charts include the following:

- Beams are designed as simply supported, typical interior beam.
- Grade 270 low relaxation seven-wire strands with a 0.6 inch diameter are used with the standard PCBT strand grid.
- PCBT concrete 28-day compressive strengths of 6 ksi, 8 ksi and 10 ksi with release strengths equal to 0.8f’c.
- A maximum of 14 draped strands can be used (7 rows of 2 strands) with drape points located at 0.4L and 0.6L. Top draped strand draped to 6” below top of top flange to clear BL05 series bar positions, but can be taken higher when necessary. Designers should conduct an analysis using the strut-and-tie model to determine anchorage zone reinforcement limits for partially draped strands [i.e., top draped strand located more than approximately 4” (shallower beam) to 8” (deeper beam) below top of beam at end of beam].
- Hold-down forces adhering to requirements found in File Nos. 12.01-7 and -8.
- Non-composite dead loads include; 3” bolster, steel diaphragm uniformly distributed dead load of 10 plf, and a 20 psf construction tolerance load.
- Deck slab thickness used:
  - 8-foot, 9-foot and 10-foot spacing: 8.5” (Includes 0.5” wearing surface)
  - 11-foot and 12-foot spacing: 9.0” (Includes 0.5” wearing surface)
- Composite dead loads include two F-Shape parapets (VDOT Standard BPB-3) distributed equally between four beams and a 15 psf future wearing surface.
- 1-foot beam end extensions beyond centerline of bearing used.
- Design Live Load: HL-93
  Legal Loads: as specified under Legal Loads (a, b and c) in current IIM-S&B-86
- The “Approximate Method” is used in computing time dependent prestressed losses.
- “Elastic Gains” are neglected in the computation of prestress loss totals.
PRELIMINARY DESIGN CHART PARAMETERS (CONT.'D):

Design parameters used for the development of the preliminary chart include the following (continued):

- Concrete Stress limits:  \( f'_c \) (psi)  \( f'_c \) (ksi)
  - Release W/ Reinforcement:  \( 7.5 \times \sqrt{f'_{ci}} \)  \( 0.24 \times \sqrt{f'_{ci}} \)
  - Release Tension (Top):  \( 3 \times \sqrt{f'_{ci}} \leq \text{max 200 psi} \)  \( 0.0984 \times \sqrt{f'_{ci}} \leq \text{max 0.20 ksi} \)
  - Release Tension (Bottom):  \( 0 \text{ psi} \)  \( 0 \text{ ksi} \)
  - Release Compression:  \( 0.6 \times f'_{ci} \)  \( 0.6 \times f'_{ci} \)
  - Service Tension* (Top):  \( 6 \times \sqrt{f'_c} \)  \( 0.19 \times \sqrt{f'_c} \)
  - Service Tension* (Bottom):  \( 6 \times \sqrt{f'_c} \)  \( 0.19 \times \sqrt{f'_c} \)
  - Service Compression:  \( 0.6 \times f'_c \)  \( 0.6 \times f'_c \)

*Moderate corrosion conditions assumed for top and bottom of beam

- Lifting stress calculations follow the methodology and recommendations found in the draft of the PCI Lateral Stability Guidelines for Prestressed Concrete Members using the following:
  - 20 mph wind load with a pressure of 2 psf
  - Lift connection rigid extension above top of beam = 0"
  - Lift connection tolerance from centerline of beam = 0.25"
  - Rebound = 0%
  - Vertical pickup from lifting embedments (2 point pick-up or single point with spreader bar)
  - A minimum factor of safety of 1.5 against both cracking and failure during lifting

  Lift connection locations were placed within a distance of 2/3H from the beam end if a minimum factor of safety of 1.5 for both cracking and failure can be maintained. For cases where a minimum factor of safety of 1.5 could not be maintained, lifting connection locations were increased up to the minimum of 4/3H and 0.07 x (beam length).

  A circle in the preliminary design chart indicates a case where lifting locations were adjusted beyond 2/3 H for the span length shown to satisfy the minimum factor of safety.

  Release strength and the draped/straight strand pattern will affect lifting stresses and changes may facilitate obtaining the minimum factor of safety for a given span.

- Prestressing of any straight strands in the top flange is not accounted for in the preliminary design runs. Designer should approximate straight strands and check both with and without during final beam design.
PRELIMINARY DESIGN CHART (f’c = 6 ksi):

Indicates design required lifting point adjustment beyond 2/3 H to meet design parameters.

Maximum Possible Span Length for f’c = 6 ksi (ft)

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Beam Spacing (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td>PCBT-93</td>
<td>144</td>
</tr>
<tr>
<td>PCBT-85</td>
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<td>PCBT-77</td>
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<td>PCBT-61</td>
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<td>PCBT-37</td>
<td>73</td>
</tr>
<tr>
<td>PCBT-29</td>
<td>58</td>
</tr>
</tbody>
</table>
PRELIMINARY DESIGN CHART (f’c = 8 ksi):

Beams nearing the maximum possible span lengths indicated below will require a large number of strands. See Design Requirements on File No. 12.03-3.

Indicates design required lifting point adjustment beyond 2/3 H to meet design parameters.

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Beam Spacing (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
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<tr>
<td>PCBT-93</td>
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<td>PCBT-85</td>
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<td>PCBT-69</td>
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<td>PCBT-37</td>
<td>84</td>
</tr>
<tr>
<td>PCBT-29</td>
<td>70</td>
</tr>
</tbody>
</table>
PRELIMINARY DESIGN CHART (f’c = 10 ksi):

Use of 10 ksi requires design approval. Beams nearing the maximum possible span lengths will require a large number of strands. See Design Requirements on File No. 12.03-3.

Indicates design required lifting point adjustment beyond 2/3 H to meet design parameters.

Maximum Possible Span Length for f’c = 10 ksi (ft)

<table>
<thead>
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<th>Beam Type</th>
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<th>10</th>
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<tr>
<td>PCBT-93</td>
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<tr>
<td>PCBT-77</td>
<td>151</td>
<td>149</td>
<td>144</td>
<td>139</td>
<td>135</td>
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<td>PCBT-69</td>
<td>146</td>
<td>140</td>
<td>136</td>
<td>131</td>
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<td>76</td>
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<td>69</td>
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PRESTRESSED CONCRETE I-BEAMS:

The AASHTO/PCI prestressed concrete I-beam sections used by the Structure and Bridge Division in the past have become less efficient with the adoption of the prestressed concrete Bulb-T sections. These sections will not be used except for widening of existing structures or replacing damaged beams.

For widening of existing structures with Types V and VI beams, the use of prestressed concrete Bulb-T's closely matching the depth of existing beams should be considered.

PRESTRESSED CONCRETE I-BEAMS SECTIONS:

The prestressed concrete I-beam sections (PCB-series) used by the Structure and Bridge Division and listed in File No. 12.04-3 along with their section properties are taken from the AASHTO/PCI Standard I-Beam sections.

For Prestressed Concrete I-Beam Preliminary Design Chart, see File Nos. 12.04-6 thru -8.

CONCRETE:

Concrete used in the design of prestressed concrete I-beams shall be Class A5 having a minimum 28 day compressive strength of 5000 psi. Concrete having strengths up to and including 10,000 psi may be used whenever it is economical or necessary to meet the design requirements of the project. Concrete strengths exceeding 10,000 psi may be used only after obtaining a design waiver.

The minimum compressive strength of concrete required at release to be specified in the General Notes shown on the title sheet of the plans shall be the computed design value rounded up to the nearest 100 psi but in no case shall it be less than 4000 psi or greater than 0.8f'c.

REINFORCEMENT:

All prestressed and non-prestressed reinforcement used in the design and fabrication of prestressed concrete I-beams shall conform to the requirements contained in File Nos. 12.01-1 and -2, and as specified below.

Prestressed concrete I-beams shall normally be designed using 0.6" diameter strands.

For draping of strands and hold-down forces, see File Nos. 12.01-7 thru -9.
COMPOSITE SECTION PROPERTIES:

In computing the composite section properties for prestressed concrete I-beams, the effects of bolster shall be neglected.

For composite prestressed construction where slabs or flanges are assumed to act integrally with the prestressed concrete I-beam, the effective flange width shall be computed in accordance with the requirements of Article 4.6.2.6 of the AASHTO LRFD specifications.

MEMBER WEIGHT AND LENGTH LIMITATIONS:

When considering a prestressed concrete I-beam section to use, the designer shall investigate the feasibility of having the member hauled to the project site and erected.

BEAM DIAPHRAGM DETAILS:

For beam diaphragm details, see File Nos. 12.10-1 thru -9.

For beam continuity diaphragm details, see File Nos. 12.15-1 thru -9.

MISCELLANEOUS BEAM DETAILS:

For camber and bolster computations, see File Nos. 12.02-1 thru -3.

For dead load deflection diagrams, see File No. 12.02-4.

For top of slab elevations along centerline of beams, see File No. 12.02-5.
<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Depth (in)</th>
<th>Area (in²)</th>
<th>Volume To Surface Ratio V/S</th>
<th>Centroid to Bottom (in)</th>
<th>Moment of Inertia I (x 10^3 in⁴)</th>
<th>Section Modulus</th>
<th>Weight @ 150 pcf</th>
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</thead>
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<tr>
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<td>36</td>
<td>369</td>
<td>3.37</td>
<td>15.83</td>
<td>50.98</td>
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<td>45</td>
<td>560</td>
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<td>20.27</td>
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<td>1013</td>
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<td>PCB-6</td>
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<td>1085</td>
<td>4.41</td>
<td>36.38</td>
<td>733.32</td>
<td>Bot: 20587</td>
<td>20157</td>
</tr>
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</table>

**Prestressed and Post-Tensioned Concrete**

**Prestressed Concrete I-Beams**

**Section Properties**

**PART 2**

**DATE:** 15Oct2015

**SHEET** 3 of 8

**FILE NO.** 12.04-3
Maximum number of strands in row 1: 6
2: 6
3: 6
4: 4
5 and higher: 2

Maximum number of strands in row 1: 8
2: 8
3: 8
4: 8
5: 6
6: 4
7 and higher: 2
Maximum number of strands in row 1: 11*
2: 11*
3: 11*
4: 11*
5: 9*
6: 7*
7: 5*
8 and higher: 3*

Maximum number of strands indicated above by asterisk (*) shall be decreased by one strand when draping two strands per row.

Maximum number of strands in row 1: 12*
2: 12*
3: 12*
4: 12*
5: 10*
6: 8*
7: 6*
8: 4*
9 and higher: 3

Maximum number of strands indicated above by asterisk (*) shall be decreased by one strand when draping three strands per row.
PRELIMINARY DESIGN CHART PARAMETERS:

The PCB Preliminary Design Chart is intended to assist the designer in selecting the most economical I-Beam section for a particular beam spacing and span length. The preliminary chart is not intended to provide a final beam design.

The PCB Preliminary Design Chart was developed in accordance with the AASHTO LRFD 7th Edition Specifications and VDOT Structure and Bridge IIM-S&B-80.5 VDOT Modifications to the AASHTO LRFD 7th Edition, using LEAP Bridge Enterprise – ConSpan Version 14.00.00.19.

Design parameters used for the development of the preliminary chart include the following:

- Beams are designed as simply supported, typical interior beam.
- Targeted flexural performance ratio of 0.90.
- Grade 270 low relaxation seven-wire strands with a 0.6 inch diameter are used with the standard PCB strand grid.
- PCB concrete 28-day compressive strength of 8 ksi, with a 6 ksi release strength (up to 0.8f'c can be used).
- A maximum of 14 draped strands can be used (7 rows of 2 strands) with drape points located at 0.4L and 0.6L where L is the span length.
- Hold-down forces adhering to requirements found in File Nos. 12.01-7 and -8.
- Non-composite dead loads include; 3” bolster, steel diaphragm uniformly distributed dead load of 10 plf, and a 20 psf construction tolerance load.
- Deck slab thickness used:
  - 6-foot spacing: 7.5in  (Includes 0.5” wearing surface)
  - 7-foot spacing: 8.0in  (Includes 0.5” wearing surface)
  - 8-foot, 9-foot and 10-foot spacing: 8.5in  (Includes 0.5” wearing surface)
- Composite dead loads include two F-Shape parapets (VDOT Standard BPB-3) and a 15 psf future wearing surface.
- 1-foot beam end extensions beyond centerline of bearing used.
- Design Live Load: HL-93
  Legal Loads: as specified under Legal Loads (a, b and c) in current IIM-S&B-86.
- The “Approximate Method” is used in computing time dependent prestressed losses.
- “Elastic Gains” are neglected in the computation of prestress loss totals.
PRELIMINARY DESIGN CHART PARAMETERS (CONT.’D):

Design parameters used for the development of the preliminary chart include the following (continued):

- Concrete Stress limits:
  - Release W/ Reinforcement: \( f'_c \) \( (psi) \)
    \[ 7.5 \times \sqrt{f'_{ci}} \]
  - Release Tension (Top): \( 3 \times \sqrt{f'_{ci}} \leq \text{max 200 psi} \)
    \[ 0.0984 \times \sqrt{f'_{ci}} \leq \text{max 0.20 ksi} \]
  - Release Tension (Bottom): 0 psi
  - Release Compression: \( 0.6 \times f'_{ci} \)
  - Service Tension* (Top): \( 6 \times \sqrt{f'_{c}} \)
    \[ 0.19 \times \sqrt{f'_{c}} \]
  - Service Tension* (Bottom): \( 6 \times \sqrt{f'_{c}} \)
    \[ 0.19 \times \sqrt{f'_{c}} \]
  - Service Compression: \( 0.6 \times f'_{c} \)
    \[ 0.6 \times f'_{c} \]

*Moderate corrosion conditions assumed for top and bottom of beam

- Lifting stress calculations follow the methodology and recommendations found in the draft of the PCI Lateral Stability Guidelines for Prestressed Concrete Members using the following:
  - 20 mph wind load with a pressure of 2 psf
  - Lift connection rigid extension above top of beam = 0"
  - Lift connection tolerance from centerline of beam = 0.25"
  - Rebound = 0%
  - Vertical pickup from lifting embedments (2 point pick-up or single point with spreader bar)
  - A minimum factor of safety of 1.5 against both cracking and failure during lifting
  - Lift connection locations were placed within a distance of 2/3H from the beam end if a minimum factor of safety of 1.5 for both cracking and failure can be maintained. For cases where a minimum factor of safety of 1.5 could not be maintained, lifting connection locations were increased up to the minimum of 4/3H and 0.07 x (beam length).

A circle in the preliminary design chart indicates a case where lifting locations were adjusted beyond 2/3 H for the span length shown to satisfy the minimum factor of safety.

Release strength and the draped/straight strand pattern will affect lifting stresses and changes may facilitate obtaining the minimum factor of safety for a given span.

- Prestressing of any straight strands in the top flange are not accounted for in the preliminary design runs. Designer should approximate straight strands and check both with and without during final beam design.
PRELIMINARY I-Beam Design Chart

Max beam lengths based on a flexural performance ratio of 0.90

<table>
<thead>
<tr>
<th>Beam Type</th>
<th>Beam Spacing (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td>PCB-2 *</td>
<td>63</td>
</tr>
<tr>
<td>PCB-3</td>
<td>90</td>
</tr>
<tr>
<td>PCB-4</td>
<td>116</td>
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<tr>
<td>PCB-5</td>
<td>136</td>
</tr>
<tr>
<td>PCB-6</td>
<td>146</td>
</tr>
</tbody>
</table>

* PCB-2 beams may need special designs for stability for the maximum span lengths shown.

Indicates design required lifting point adjustment beyond 2/3 H to meet design parameters.
PRESTRESSED CONCRETE VOIDED SLAB SECTIONS:

The prestressed concrete voided slab sections used by the Structure and Bridge Division and listed in File No. 12.05-5 along with their section properties are taken from the AASHTO/PCI standard voided slab sections with modifications made to the longitudinal shear key details and width of end diaphragms.

Prestressed concrete voided slabs shall not be used on bridges with the following roadway functional classifications:

- Freeways
- Urban/Rural Principal Arterial

Prestressed concrete voided slabs may be used on all other roadway functional classifications as follows:

<table>
<thead>
<tr>
<th>Design Year ADT</th>
<th>Design Year ADTT</th>
<th>Deck / Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 4000</td>
<td>≤ 100</td>
<td>Asphalt Overlay (Secondary System only) *</td>
</tr>
<tr>
<td>&gt; 4000</td>
<td>100 &lt; ADTT ≤ 200</td>
<td>Concrete deck 5” thick with single layer of reinforcement</td>
</tr>
<tr>
<td>&gt; 4000</td>
<td>&gt; 200</td>
<td>Concrete deck 7 ½” thick with two layers of reinforcement</td>
</tr>
</tbody>
</table>

* Asphalt overlays are prohibited for structures on the Primary System regardless of the roadway functional classification and Design Year ADT. Concrete decks shall be used for structures utilizing prestressed concrete voided slabs on the Primary System.

For Prestressed Concrete Voided Slab Preliminary Design Chart, see File Nos. 12.05-7 thru -9.

Concrete:

Concrete used in the design of prestressed concrete voided slabs shall be Class A5 having a minimum 28 day compressive strength of 5000 psi.

The minimum compressive strength of concrete at release shall be 4000 psi and shall be specified in the General Notes shown on the title sheet of the plans.

Reinforcement:

All prestressed and non-prestressed reinforcement used in the fabrication and design of prestressed concrete voided slabs shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

Prestressing strands used in the design of prestressed concrete voided slabs shall normally be designed using 0.6” diameter Prestressing strands.
COMPOSITE CONCRETE DECK / OVERLAY:

For composite prestressed construction where the concrete deck/overlay is assumed to act integrally with the prestressed concrete voided slab section, shear transfer reinforcement shall be provided in accordance with the provisions of contained in Article 5.7.4 of the AASHTO LRFD specifications shall be used.

Concrete:

Concrete used in the concrete deck/overlay shall be Class A4 having a minimum 28 day compressive strength of 4000 psi.

Reinforcement:

The minimum reinforcement in the concrete deck/overlay as follows:

For 5” thick overlay, one layer of #4 @ 12” in both directions;

For 7 ½” thick overlay, two layers of #4 @ 12” in both directions;

For multiple spans, additional #4 @ 12” over piers extending at least to the quarter points of adjacent spans.

VOID FORMS:

All formwork shall conform to the requirements contained in Section 405.05(a) of the VDOT Road and Bridge Specifications and as specified below.

The material used to form internal voids for voided slab sections shall be expanded polystyrene having a maximum water absorption (by volume) rate of 10%.

The use of waxed-coated cardboard tubes shall not be permitted.

TRANSVERSE POST-TENSIONED TENDONS:

When the length of transverse tendon required is < 20 feet, tendons shall be 1 1/4” diameter galvanized structural rods conforming to ASTM A449 with threaded ends.

When the length of transverse tendon required is ≥ 20 feet, tendons may be either 1/2” diameter coated, low-relaxation Grade 270 strand (Polystrand or equal) or 1 1/4” diameter galvanized structural rods conforming to ASTM A449 with threaded ends.
TRANSVERSE CONNECTION DETAIL TYPES:

Two types of transverse connection details are available for use for prestressed concrete voided slabs: Transverse Tendon and Virginia Adjacent Member Connections (VAMC).

For asphalt overlays, VAMC details shall be used where skew exceeds 10 degrees. For the remaining cases, contact the District Structure and Bridge Engineer for design approval on which detail type to use.

Transverse Tendon Details:

Transverse Tendon details use coated, low-relaxation Grade 270 strand (Polystrand or equal) or galvanized structural rods running through the slabs. For skews ≤ 10°, tendons can extend through all members on skew and shear keys shall be grouted with Engineered Cementitious Concrete (ECC) prior to post-tensioning. For skews > 10°, galvanized structural rods perpendicular to the slab centerline shall be used connecting 2 members at a time. Grouting of shear keys with ECC shall take place after post-tensioning for skews > 10°.

See File No. 12.05-12 for sample Erection Diagram sheet illustrating details utilizing transverse tendons details with skew > 10°.

VAMC Details:

VAMC details use blockouts along interior edges of slabs for placing bars across the shear key interface at 2'-0" intervals. Very High Performance Concrete (VHPC) is used to fill the shear key and block out area to fully develop the bars. The overall longitudinal VAMC blockout dimension is to extend between 0.25 and 0.75 of the span rounded up to an even 6-foot interval. This interval allows the use of reusable standard blockout forms with slits at 2'-0" intervals to accommodate the top slab bars extending into the blockout area. See File No. 12.05-11 for blockout dimentsions.

Increase design construction tolerance allowance from 10 to 17 psf when VAMC details are used.

See File No. 12.05-13 for sample Erection Diagram sheet illustrating details utilizing VAMC details with skew > 10°.

TRANSVERSE TENDON OR INTERNAL DIAPHRAGM SPACING:

The spacing of transverse post-tensioned tendons shall be as follows:

- For ends of prestressed concrete voided slabs constrained from lateral movement by wing haunches cast tight against the slabs:
  - For spans ≤ 30 feet: at mid-span (1 tie)
  - For spans ≤ 60 feet: at 1/3 points (2 ties)
  - For spans > 60 feet: at 1/4 points (3 ties)
TRANSVERSE TENDON OR INTERNAL DIAPHRAGM SPACING (Cont’d):

The spacing of transverse post-tensioned tendons shall be as follows (cont’d):

- For ends of prestressed concrete voided slabs not constrained from lateral movement:
  - For spans ≤ 30 feet: at mid-span and at each end (3 ties)
  - For spans ≤ 60 feet: at 1/3 points and at each end (4 ties)
  - For spans > 60 feet: at 1/4 points and at each end (5 ties)

Transverse tendons are not required when VAMC details are used, but solid sections (breaks in voids serving as interior diaphragms) are required at the same intervals.

WATERPROOFING REQUIREMENTS:

For prestressed concrete voided slabs that will not be protected by a 5” minimum cast-in-place deck slab (i.e., asphalt overlay):

The entire deck (i.e., the top surfaces of voided slabs) shall be waterproofed in accordance with the requirements of Sections 405 and 416 of VDOT’s Road and Bridge Specifications.

For all prestressed concrete voided slabs:

Exterior side of exterior slabs, including drip bead, shall be waterproofed at precast fabrication plant with a two coat epoxy resin system. All areas damaged during shipment and erection shall be repaired after erection.

For waterproofing longitudinal shear keys, see File No. 12.05-10 and -11.

S&B STANDARD DETAIL SHEETS AND CELL LIBRARIES:

Standards for prestressed concrete voided slabs, PST series, Transverse Tendons, and PSV series, Virginia Alternate Member Connection (VAMC) details, are located in Part 5 of this manual along with the corresponding cell libraries.

SAMPLE SPECIAL PROVISIONS:

Sample special provisions for Engineered Cementitious Composite (ECC) and Very High Performance Concrete (VHPC) are available from the Central Office Structure and Bridge Engineering Services Program Area.
### Table: Section Properties and Strand Pattern Layout

<table>
<thead>
<tr>
<th>Width (W ft)</th>
<th>Depth (D in)</th>
<th>Void Diameter</th>
<th>A (in)</th>
<th>B (in)</th>
<th>C (in)</th>
<th>E (in)</th>
<th>Net Area (in²)</th>
<th>Moment of Inertia (in⁴)</th>
<th>Section Modulus (in⁴)</th>
<th>Weight @ 150 pcf (lbs/lin. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>15</td>
<td>8</td>
<td>10</td>
<td>16</td>
<td>7.5</td>
<td>6</td>
<td>439</td>
<td>9725</td>
<td>1296</td>
<td>457</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>10</td>
<td>10</td>
<td>16</td>
<td>9</td>
<td>7.5</td>
<td>491</td>
<td>16514</td>
<td>1835</td>
<td>511</td>
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<tr>
<td>3</td>
<td>21</td>
<td>12</td>
<td>10</td>
<td>16</td>
<td>10.5</td>
<td>9</td>
<td>530</td>
<td>25747</td>
<td>2452</td>
<td>552</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>8</td>
<td>10</td>
<td>14</td>
<td>7.5</td>
<td>6</td>
<td>569</td>
<td>12897</td>
<td>1720</td>
<td>593</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>10</td>
<td>10</td>
<td>14</td>
<td>9</td>
<td>7.5</td>
<td>628</td>
<td>21855</td>
<td>2428</td>
<td>654</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>12</td>
<td>10</td>
<td>14</td>
<td>10.5</td>
<td>9</td>
<td>703</td>
<td>34517</td>
<td>3287</td>
<td>733</td>
</tr>
</tbody>
</table>

Weight provided is for section with voids and shear keys. Solid sections for transverse tendons/internal diaphragms should be entered as point loads and filled shear key weight as uniform load for design.
All strand positions shall be on a 2” by 2” grid including any courtesy strand locations. For slabs with drainage inserts or anchor bolt sleeves, additional strand positions will not be feasible and the Designer shall identify additional conflicts and not detail strands in those positions.

<table>
<thead>
<tr>
<th>Slab Size</th>
<th>Max. Number of Strands Per Row Y1 Y2 Y3 Y4 Y5 Y6</th>
<th>Row 1</th>
<th>Row 2</th>
<th>Row 3</th>
<th>Row 4</th>
<th>Row 5</th>
<th>Row 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'-0&quot; x 15&quot;</td>
<td>14 8 0 2 6 6</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>8 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
</tr>
<tr>
<td>3'-0&quot; x 18&quot;</td>
<td>14 8 0 2 6 6</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
<td>14 ¼</td>
</tr>
<tr>
<td>3'-0&quot; x 21</td>
<td>14 8 4 2 8 10</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>14 ¼</td>
<td>16 ¼</td>
<td>18 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 15&quot;</td>
<td>20 10 0 2 6 8</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>8 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 18&quot;</td>
<td>20 10 0 2 4 8</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
<td>14 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 21&quot;</td>
<td>20 12 6 2 8 16</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>12 ¼</td>
<td>16 ¼</td>
<td>18 ¼</td>
</tr>
</tbody>
</table>

Number and distances shown are for interior slabs with transverse tendon sleeves (i.e., no tendon blockouts) at positions shown in Section Property table on File No. 12.05-5. For slabs with tendon blockouts (exterior slabs or interior slabs with skews > 10°), additional strand positions will not be feasible and shall be identified by the Designer.

<table>
<thead>
<tr>
<th>Slab Size</th>
<th>Max. Number of Strands Per Row Y1 Y2 Y3 Y4 Y5 Y6</th>
<th>Row 1</th>
<th>Row 2</th>
<th>Row 3</th>
<th>Row 4</th>
<th>Row 5</th>
<th>Row 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'-0&quot; x 15&quot;</td>
<td>14 8 4 2 4 4</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>8 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
</tr>
<tr>
<td>3'-0&quot; x 18&quot;</td>
<td>14 8 4 4 2 4</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
<td>14 ¼</td>
</tr>
<tr>
<td>3'-0&quot; x 21</td>
<td>14 8 4 2 4 6</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>12 ¼</td>
<td>16 ¼</td>
<td>18 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 15&quot;</td>
<td>20 10 4 2 4 8</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>8 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 18&quot;</td>
<td>20 10 4 4 2 6</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>10 ¼</td>
<td>12 ¼</td>
<td>14 ¼</td>
</tr>
<tr>
<td>4'-0&quot; x 21&quot;</td>
<td>20 12 6 2 6 12</td>
<td>2 ¼</td>
<td>4 ¼</td>
<td>6 ¼</td>
<td>12 ¼</td>
<td>16 ¼</td>
<td>18 ¼</td>
</tr>
</tbody>
</table>

Number and distances shown account for VAMC blockouts and stirrup shape.
PRELIMINARY DESIGN CHART PARAMETERS:

The Voided Slab Preliminary Design Chart is intended to assist the designer in selecting the most economical voided slab unit for a particular span length and design Average Daily Truck Traffic. The preliminary chart is not intended to provide a final slab unit design.

The Voided Slab Preliminary Design Chart was developed in accordance with the AASHTO LRFD 7th Edition Specifications and VDOT Structure and Bridge IIM 80.5 VDOT Modifications to the AASHTO LRFD 7th Edition, using LEAP Bridge Enterprise – ConSpan Version 14.00.00.19.

Design parameters used for the development of the preliminary design chart include the following:

- Voided slab units are designed as simply supported, typical interior unit
- Targeted flexural performance ratio of 0.9 (acceptable range of performance ratios 0.88 to 0.92)
- Grade 270 low relaxation seven-wire strands with a \( \frac{1}{2} \)" diameter are used with the standard strand grid and a 4" minimum side distance to the center of the first strand. Designers should use 0.6" diameter strand, 3" minimum side distance and leave the strand position in stirrup corners empty per current requirements.
- Concrete 28-day compressive strength of 5000 psi, with a 4000 psi release strength
- Non-composite dead loads include: 10 psf construction tolerance load. Designers shall use 17 psf where Virginia Adjacent Member Connection details are used.
- Wearing surface depth and types considered:
  - 1 7/8" Asphalt Overlay for 3’ wide units or 2 ¼" Asphalt Overlay for 4’ wide units
  - 5" Non-Composite Concrete Deck Topping
  - 7 ½" Composite Concrete Deck
- No future wearing surface load has been included in the analysis
- Composite dead loads include two F-Shape parapets (VDOT Standard BPB-3)
- LRFD Live Load Distributions Factors for moment equal to:
  - 3ft wide slab: 0.35
  - 4ft wide slab: 0.45
  - Shear All Units: AASHTO
- Design Live Load: HL-93
  Legal Loads: as specified under Legal Loads (a, b and c) in current IIM-S&B-86
PRELIMINARY DESIGN CHART PARAMETERS (Cont’d):

Design parameters used for the development of the preliminary design chart include the following:

- The “Approximate Method” is used in computing time dependent prestressed losses.
- “Elastic Gains” are to be neglected in the computation of prestress loss totals.

- Concrete Stress limits:
  - Release W/ Reinforcement: 
    - $7.5 \times \sqrt{f'_{ci}}$ psi, $0.24 \times \sqrt{f'_{ci}}$ ksi
  - Release Tension (Top): 
    - $3 \times \sqrt{f'_{ci}} \leq$ max 200 psi, $0.0984 \times \sqrt{f'_{ci}} \leq$ max 0.20 ksi
  - Release Tension (Bottom): 
    - 0 psi, 0 ksi
  - Release Compression: 
    - $0.6 \times f'_{ci}$ psi, $0.6 \times f'_{ci}$ ksi
  - Service Tension* (Top): 
    - $6 \times \sqrt{f'_{c}}$ psi, $0.19 \times \sqrt{f'_{c}}$ ksi
  - Service Tension* (Bottom): 
    - $6 \times \sqrt{f'_{c}}$ psi, $0.19 \times \sqrt{f'_{c}}$ ksi
  - Service Compression: 
    - $0.6 \times f'_{c}$ psi, $0.6 \times f'_{c}$ ksi

*Moderate corrosion conditions assumed for top and bottom of beam

- 1ft Beam End Extensions beyond centerline of bearing
Preliminary AASHTO Voided Slab Unit Design Chart

Max span lengths based on a flexural performance ratio of 0.90 and f'c=5ksi

Maximum Possible Span Length (ft) for f'c = 5 ksi

<table>
<thead>
<tr>
<th>Unit</th>
<th>Asphalt Overlay</th>
<th>5&quot; Non-Composite Concrete Deck</th>
<th>7.5&quot; Composite Concrete Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>SII-36</td>
<td>31</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>SIiII-36</td>
<td>38</td>
<td>37</td>
<td>44</td>
</tr>
<tr>
<td>SIV-36</td>
<td>45</td>
<td>44</td>
<td>49</td>
</tr>
<tr>
<td>SII-48</td>
<td>32</td>
<td>31</td>
<td>38</td>
</tr>
<tr>
<td>SIiII-48</td>
<td>39</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>SIV-48</td>
<td>46</td>
<td>44</td>
<td>50</td>
</tr>
</tbody>
</table>
Shear key detail above shown for 21" deep slab void size and precast hole position, similar for other slabs.

All keyway surfaces shall be cleaned of all dirt, laitance and loose aggregate by means of sandblasting and prewetted with clean water prior to the grouting of shear keys.

Grout used for shear keys shall be Engineered Cementitious Composite (ECC). Grouting of shear keys shall be done in one continuous operation without interruption for the entire length of the shear keys for each span. Sample special provision for Engineered Cementitious Composite (ECC) is available from the Central Office Structure and Bridge Engineering Services Program Area.

Surfaces to receive the waterproofing system shall be prepared in accordance with the requirements of Section 429 of VDOT’s 2016 Road and Bridge Specifications.

Joint fabric from the VDOT Special Products Evaluation List under Joint Fabrics shall be used. For installation procedures and waterproofing details for asphalt and concrete overlays, see Standards PST-6A and -6B respectively in Part 5 of this manual.

Post-tensioning of transverse tendons (except where tendons connect two slabs at a time for bridges on skew) and the casting of parapets shall not be done until the strength of the ECC in the shear key has reached a compressive strength of at least 4000 psi.
All keyway surfaces shall be cleaned of all dirt, laitance and loose aggregate by means of sandblasting and prewetted with clean water prior to the filling of shear keys and VAMC blockouts.

Very High Performance Concrete (VHPC) shall be used to fill shear keys and VAMC blockouts. Filling of shear keys and VAMC blockouts shall be done in one continuous operation without interruption for the entire length of the shear keys for each span. Sample special provision for Very High Performance Concrete (VHPC) is available from the Central Office Structure and Bridge Engineering Services Program Area.

Epoxy and joint fabric shall not be placed until the VHPC has cured for 28 days unless the Contractor tests trial patches and obtains passing results per Section 431 of VDOT’s 2016 Road and Bridge Specifications. Surfaces to receive the waterproofing system shall be prepared in accordance with the requirements of Section 429 of VDOT’s 2016 Road and Bridge Specifications.

Joint fabric from the VDOT Special Products Evaluation List under Joint Fabrics shall be used. Two strips are required for the length of the VAMC blockout and a single strip required for the remaining length of bridge as indicated in the details above. For installation procedures and waterproofing details for asphalt and concrete overlays, see Standards PSV-6A and -6B respectively in Part 5 of this manual.
Notes:

- Transverse bars shall be 1 1/8"-diameter galvanized structural rods conforming to ASTM A490 with threaded ends tensioned to 30,000 lbs.
- The rod shall have a washer and nut at each end. Rods, nuts, washers, and structural rod tensioned to 30,000 lbs. are to be provided in accordance with the specifications of the Engineer.
- The Contractor may use galvanized couplers to tie the transverse rods between Stage I and Stage II and tension to 30,000 lbs.
- Contractor to verify location of recesses based on setting sequence.
- Contractor shall verify location of inserts for temporary traffic barrier before setting Slab Type II.

For waterproofing details and installation procedure, see sheet 16.
ERECTION DIAGRAM

Continuous VAMC blockouts not shown for, but typical for, all members.

Notations:
- 
- inserts for temporary traffic barrier before setting Slab Type II.
- SD0401 and SD0502 bars are included in the Reinforcing Steel Schedule for Superstructure.
- for waterproofing details and installation procedure, see sheet 16.

SAFETY PRECAUTIONS

- Wear eye protection.
- Wear protective clothing.
- Keep hands and feet away from machinery.

PRECAST CONCRETE DETAILS

- Typical insert spacing shown.
- Typical insert spacing shown for Slab Type II.
- Section 06:00:00.
- Section 06:25:00.
- Section 06:00:00.
- Section 06:25:00.
- Section 06:00:00.
- Section 06:25:00.
- Section 06:00:00.
- Section 06:25:00.

Shear Key Details

- One strip required for shear key waterproofing detail, sheet 06:00.
- Scale: 3" = 1'-0"
PRESTRESSED CONCRETE BOX BEAMS:

The prestressed concrete box beam sections used by the Structure and Bridge Division and listed in File No.12.06-6 along with their section properties are taken from the AASHTO/PCI standard box beam sections with modifications made to the longitudinal shear key details and width of end diaphragms.

Prestressed concrete box beams shall not be used on bridges with the following roadway functional classifications:

- Freeways
- Urban/Rural Principal Arterial

Prestressed concrete box beams may be used on all other roadway functional classifications as follows:

<table>
<thead>
<tr>
<th>Design Year ADT</th>
<th>Design Year ADTT</th>
<th>Deck / Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 4000</td>
<td>≤ 100</td>
<td>Asphalt Overlay (Secondary System only) *</td>
</tr>
<tr>
<td>&gt; 4000</td>
<td>100 &lt; ADTT ≤ 200</td>
<td>Concrete deck 5” thick with single layer of reinforcement</td>
</tr>
<tr>
<td>&gt; 4000</td>
<td>&gt; 200</td>
<td>Concrete deck 7 ½” thick with two layers of reinforcement</td>
</tr>
</tbody>
</table>

* Asphalt overlays are prohibited for structures on the Primary System regardless of the roadway functional classification and Design Year ADT. Concrete decks shall be used for structures utilizing prestressed concrete box beams on the Primary System.

Prestressed concrete box beams shall not be used without a design waiver approved by the State Structure and Bridge Engineer for use outside the roadway functional classifications and/or deck/overlay requirements indicated above.

The use of prestressed concrete box beams may be justified when considering, but not limited to, the following pertinent site specific parameters:

1. **Hydraulics**

   Prestressed concrete box beam spans often provide the shallowest superstructure alternative, hence the most favorable from a hydraulic perspective. For superstructure replacements, the shallowest possible superstructure may satisfy an “in-kind” hydraulic analysis thus avoiding the substantial cost and time of a site survey and a full blown hydraulic analysis.

2. **Heavy Debris Laden Streams/Rivers**

   Prestressed concrete box beam spans provide a smooth bottom to the superstructure which allows greater passage of debris beneath the structure as opposed to beam/girder spans which are prone to catching debris beneath the structure thus leading to larger debris blockages. Debris can no longer be left to continue on its course. Maintenance crews must remove the debris from the stream, often by the use of a crane and the debris is then trucked from the site at a considerable monetary cost and opportunity (time) cost to the maintenance crew. Contact the District Bridge Engineer for information and recommendation.
3. Rapid Bridge Construction

The time it takes to construct a prestressed concrete box beam superstructure to the extent that it can provide for the controlled passage of vehicles can be as little as days or even hours if necessary. Short term closings in lieu of expensive detours can often be negotiated with the municipality and the immediate community with the benefit of providing substantial project cost and user cost saving.

PRESTRESSED CONCRETE BOX BEAM SECTIONS:

The prestressed concrete box beam sections along with their section properties listed in File No. 12.06-6 are taken from the AASHTO/PCI standard box beam sections with modifications made to the longitudinal shear key details and thickness of top and bottom flanges.

Concrete:

Concrete used in the design of prestressed concrete box beams shall be Class A5 having a minimum 28 day compressive strength of 5000 psi.

The minimum compressive strength of concrete required at release to be specified in the General Notes shown on the front sheet of the plans shall be the computed design value rounded up to the nearest 100 psi but in no case shall it be less than 4000 psi.

Reinforcement:

All prestressed and non-prestressed reinforcement used in the design and fabrication of prestressed concrete box beams shall conform to the requirements contained in File Nos. 12.01-1 and -2, and as specified below.

Prestressing strands used in the design of prestressed concrete box beams shall normally be designed using 0.6” diameter prestressing strands.
COMPOSITE CONCRETE DECK / OVERLAY:

For composite prestressed construction where the concrete deck/overlay is assumed to act integrally with the prestressed concrete box beam section, shear transfer reinforcement shall be provided in accordance with the provisions of contained in Article 5.7.4 of the AASHTO LRFD specifications shall be used.

Concrete:

Concrete used in the concrete deck/overlay shall be Class A4 having a minimum 28 day compressive strength of 4000 psi.

Reinforcement:

The minimum reinforcement in the concrete deck/overlay as follows:

For 5" thick overlay, one layer of #4 @ 12" in both directions;

For 7 ½" thick overlay, two layers of #4 @ 12" in both directions;

For multiple spans, additional #4 @ 12" over piers extending at least to the quarter points of adjacent spans.

VOID FORMS:

All formwork shall conform to the requirements contained in Section 405.05(a) of the VDOT Road and Bridge Specifications and as specified below.

The material used to form internal voids for prestressed box beam sections shall be expanded polystyrene having a maximum water absorption (by volume) rate of 10%.

The use of waxed-coated cardboard tubes shall not be permitted.

TRANSVERSE POST-TENSIONED TENDONS:

When the length of transverse tendon required is < 20 feet, tendons shall be 1 1/4" diameter galvanized structural rods conforming to ASTM A449 with threaded ends.

When the length of transverse tendon required is ≥ 20 feet, tendons may be either 1½" diameter coated, low-relaxation Grade 270 strand (Polystrand or equal) or 1 1/4" diameter galvanized structural rods conforming to ASTM A449 with threaded ends.
TRANSVERSE CONNECTION DETAIL TYPES:

Two types of transverse connection details are available for use for prestressed concrete box beams: Transverse Tendon and Virginia Alternate Member Connections (VAMC).

For asphalt overlays, VAMC details shall be used where skew exceeds 10 degrees. For the remaining cases, contact the District Structure and Bridge Engineer for design approval on which detail type to use.

Transverse Tendon Details:

Transverse Tendon details use coated, low-relaxation Grade 270 strand (Polystrand or equal) or galvanized structural rods running through the beams. For skews ≤ 10°, tendons can extend through all members on skew and shear keys shall be grouted with Engineered Cementitious Concrete (ECC) prior to post-tensioning. For skews > 10°, galvanized structural rods perpendicular to the slab centerline shall be used connecting 2 members at a time. Grouting of shear keys with ECC shall take place after post-tensioning for skews > 10°.

See File No. 12.06-12 for sample Erection Diagram sheet illustrating details utilizing transverse tendons details with skew > 10°.

VAMC Details:

VAMC details use blockouts along interior edges of beams for placing bars across the shear key interface at 2'-0" intervals. Very High Performance Concrete (VHPC) is used to fill the shear key and block out area to fully develop the bars. The overall longitudinal VAMC blockout dimension is to extend between 0.25 and 0.75 of the span rounded up to an even 6-foot interval. This interval allows the use of reusable standard blockout forms with slits at 2'-0" intervals to accommodate the top beam bars extending into the blockout area. See File No. 12.06-11 for blockout dimensions.

Increase design construction tolerance allowance from 10 to 17 psf when VAMC details are used.

See File No. 12.06-13 for sample Erection Diagram sheet illustrating details utilizing VAMC details with skew > 10°.

TRANSVERSE TENDONS OR INTERNAL DIAPHRAGM SPACING:

One transverse tendon shall be provided 9" from the bottom of beam for 27" and 33" deep box beam sections. Two transverse tendons shall be provided (9" from the beam top and bottom) for 39" and 42" deep box beam sections.

The longitudinal spacing of transverse tendons shall be as follows:

- For ends of prestressed concrete box beams constrained from lateral movement by wing haunches cast tight against the slabs:
  
  For spans ≤ 60 feet: at $\frac{1}{3}$ points (2 ties)
  
  For spans > 60 feet: at $\frac{1}{4}$ points (3 ties)
TRANSVERSE TENDONS OR INTERNAL DIAPHRAGM SPACING (Cont’d):

The longitudinal spacing of transverse tendons shall be as follow (cont’d):

- For ends of prestressed concrete box beams not constrained from lateral movement:
  - For spans ≤ 60 feet: at $\frac{1}{3}$ points and at each end (4 ties)
  - For spans > 60 feet: at $\frac{1}{4}$ points and at each end (5 ties)

Transverse tendons are not required when VAMC details are used for 27” and 33” box beam depths, but solid sections (breaks in voids serving as interior diaphragms) are required at the same intervals. Transverse tendons are required in the bottom of 39” and 42” box beam depths (i.e., top tendons can be eliminated).

WATERPROOFING REQUIREMENTS:

For prestressed concrete box beams with asphalt overlay:

The entire deck (i.e., the top surfaces of box beams) shall be waterproofed in accordance with the requirements of Sections 405 and 416 of VDOT’s Road and Bridge Specifications.

For all prestressed concrete box beams:

Exterior side of exterior beams, including drip bead, seal be waterproofed at precast fabrication plant with a two coat epoxy resin system. All areas damaged during shipment and erection shall be repaired after erection.

For waterproofing longitudinal shear keys, see File No. 12.06-10 and -11.

S&B STANDARD DETAIL SHEETS AND CELL LIBRARIES:

Standards for prestressed concrete box beams, PBT series (with Transverse Tendons) and PBV series (with Virginia Alternate Member Connection (VAMC)), are located in Part 5 of this manual along with the corresponding cell libraries.

SAMPLE SPECIAL PROVISIONS:

Sample special provisions for Engineered Cementitious Composite (ECC) and Very High Performance Concrete (VHPC) are available from the Central Office Structure and Bridge Engineering Services Program Area.
We note that drifts are shown

Prestressing strands

\[ \text{Width} \times \text{Depth} \]

<table>
<thead>
<tr>
<th>Width (ft)</th>
<th>Depth (in)</th>
<th>Net Area (in²)</th>
<th>Centroid to Bottom (in)</th>
<th>Moment of Inertia (in⁴)</th>
<th>Section Modulus</th>
<th>Weight @ 150 pcf (lbs/lin. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>27</td>
<td>580</td>
<td>13.31</td>
<td>51070</td>
<td>3731</td>
<td>3836</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>640</td>
<td>16.25</td>
<td>86820</td>
<td>5183</td>
<td>5343</td>
</tr>
<tr>
<td>3</td>
<td>39</td>
<td>700</td>
<td>19.20</td>
<td>134100</td>
<td>6771</td>
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<tr>
<td>3</td>
<td>42</td>
<td>730</td>
<td>20.68</td>
<td>162400</td>
<td>7614</td>
<td>7853</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>724</td>
<td>13.35</td>
<td>67380</td>
<td>4937</td>
<td>5047</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>784</td>
<td>16.30</td>
<td>113500</td>
<td>6795</td>
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<td>844</td>
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<td>874</td>
<td>20.73</td>
<td>209500</td>
<td>9847</td>
<td>10110</td>
</tr>
</tbody>
</table>

Weight provided is for section with void and shear keys. Solid sections for transverse tendons/internal diaphragms should be entered as point loads and filled shear key weight as uniform load for design.
PRELIMINARY DESIGN CHART PARAMETERS:

The Box Beam Preliminary Design Chart is intended to assist the designer in selecting the most economical Box Beam section for a particular beam spacing and span length. The Design Chart is not intended to provide a final beam design.

The Box Beam Preliminary Design Chart was developed in accordance with the AASHTO LRFD 7th Edition Specifications and VDOT Structure and Bridge IIM 80.5 VDOT Modifications to the AASHTO LRFD 7th Edition, using LEAP Bridge Enterprise – ConSpan Version 14.00.00.19.

Design parameters used for the development of the preliminary design chart include the following:

- Beams are designed as simply supported, typical interior beam
- Targeted flexural performance ratio of 0.90
- Grade 270 low relaxation seven-wire strands with a 1/2" diameter are used with the standard strand grid and a 4" minimum side distance to the center of the first strand. Designers should use 0.6” diameter strand, 3” minimum side distance and leave the strand position in stirrup corners empty per current requirements.
- Concrete 28-day compressive strength of 5000 psi, with a 4000 psi release strength
- Non-composite dead loads include: Concrete diaphragm uniformly distributed dead load of 10 plf, and a 10 psf construction tolerance load. Designers shall use 17 psf where Virginia Adjacent Member Connection details are used.
- Wearing surface depth and types considered:
  - 1 7/8" Asphalt Overlay
  - 5" Non-Composite Concrete Deck Topping
  - 7 ½” Composite Concrete Deck
- No future wearing surface load has been included in the analysis
- Composite dead loads include two F-Shape parapets (VDOT Standard BPB-3)
- LRFD Live Load Distributions Factors for moment equal to:
  - 3ft wide slab: 0.35
  - 4ft wide slab: 0.45
  - Shear All Units: AASHTO
- Design Live Load: HL-93
  Legal Loads: as specified under Legal Loads (a, b and c) in current IIM-S&B-86
PRELIMINARY DESIGN CHART PARAMETERS (Cont’d):

Design parameters used for the development of the preliminary design chart include the following:

- The “Approximate Method” is used in computing time dependent prestressed losses.
- “Elastic Gains” are to be neglected in the computation of prestress loss totals.

- Concrete Stress limits:
  - Release W/ Reinforcement: 
    - $f'_c$ (psi): $7.5 \times \sqrt{f'_{ci}}$
    - $f'_c$ (ksi): $0.24 \times \sqrt{f'_{ci}}$
  - Release Tension (Top): $3 \times \sqrt{f'_{ci}} \leq \text{max 200 psi}$
  - Release Tension (Bottom): 0 psi
  - Release Compression: 0 psi
  - Service Tension* (Top): $6 \times \sqrt{f'_c}$
  - Service Tension* (Bottom): $6 \times \sqrt{f'_c}$
  - Service Compression: $0.6 \times f'_c$

  *Moderate corrosion conditions assumed for top and bottom of beam

- 1ft Beam End Extensions beyond centerline of bearing
### Preliminary AASHTO Box Beam Design Chart

Max span lengths based on a flexural performance ratio of 0.90 and $f'c=5\text{ksi}$

#### Maximum Possible Span Length (ft) for $f'c = 5$ ksi

<table>
<thead>
<tr>
<th>Unit</th>
<th>Asphalt Overlay</th>
<th>5” Non-Composite Concrete Deck</th>
<th>7.5” Composite Concrete Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI-36</td>
<td>57</td>
<td>55</td>
<td>61</td>
</tr>
<tr>
<td>BII-36</td>
<td>68</td>
<td>66</td>
<td>71</td>
</tr>
<tr>
<td>BIll-36</td>
<td>78</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td>BIV-36</td>
<td>83</td>
<td>80</td>
<td>84</td>
</tr>
<tr>
<td>BI-48</td>
<td>58</td>
<td>56</td>
<td>62</td>
</tr>
<tr>
<td>BII-48</td>
<td>69</td>
<td>67</td>
<td>71</td>
</tr>
<tr>
<td>BIll-48</td>
<td>79</td>
<td>77</td>
<td>81</td>
</tr>
<tr>
<td>BIV-48</td>
<td>85</td>
<td>81</td>
<td>86</td>
</tr>
</tbody>
</table>
Shear key detail shown above is for 27" and 33" deep box beams where top transverse tendons are not required. 39" and 42" box beams similar, but with transverse tendon 9" from top of beam.

All keyway surfaces shall be cleaned of all dirt, laitance and loose aggregate by means of sandblasting and prewetted with clean water prior to the grouting of shear keys.

Grout used for shear keys shall be Engineered Cementitious Composite (ECC). Grouting of shear keys shall be done in one continuous operation without interruption for the entire length of the shear keys for each span. Sample special provision for Engineered Cementitious Composite (ECC) is available from the Central Office Structure and Bridge Engineering Services Program Area.

Surfaces to receive the waterproofing system shall be prepared in accordance with the requirements of Section 429 of VDOT’s 2016 Road and Bridge Specifications.

Joint fabric from the VDOT Special Products Evaluation List under Joint Fabrics shall be used. For installation procedures and waterproofing details for asphalt and concrete overlays, see Standards PBT-6A and -6B respectively in Part 5 of this manual.

Post-tensioning of transverse tendons (except where tendons connect two beams at a time for bridges on skew) and the casting of parapets shall not be done until the strength of the ECC in the shear key has reached a compressive strength of at least 4000 psi.
All keyway surfaces shall be cleaned of all dirt, laitance and loose aggregate by means of sandblasting and prewetted with clean water prior to the filling of shear keys and VAMC blockouts.

Very High Performance Concrete (VHPC) shall be used to fill shear keys and VAMC blockouts. Filling of shear keys and VAMC blockouts shall be done in one continuous operation without interruption for the entire length of the shear keys for each span. Sample special provision for Very High Performance Concrete (VHPC) is available from the Central Office Structure and Bridge Engineering Services Program Area.

Epoxy and joint fabric shall not be placed until the VHPC has cured for 28 days unless the Contractor tests trial patches and obtains passing results per Section 431 of VDOT’s 2016 Road and Bridge Specifications. Surfaces to receive the waterproofing system shall be prepared in accordance with the requirements of Section 429 of VDOT’s 2016 Road and Bridge Specifications.

Joint fabric from the VDOT Special Products Evaluation List under Joint Fabrics shall be used. Two strips are required the length of the VAMC blockout and a single strip required for the remaining length of bridge as indicated in the details above. For installation procedures and waterproofing details for asphalt and concrete overlays, see Standards PBV-6A and -6B respectively in Part 5 of this manual.

Post-tensioning of transverse tendons in the bottom of 39” and 42” box beams may occur prior to placing the VHPC. The casting of parapets shall not be done until the strength of the VHPC in the shear key and VAMC blockout has reached a compressive strength of at least 4000 psi.
**PRESTRESSED AND POST-TENSIONED CONCRETE**

**PRESTRESSED CONCRETE BOX BEAMS**

**SAMPLE ERECTION DIAGRAM; TRANSV. TENDONS; PRESTRESSED AND POST-TENSIONED CONCRETE**

**SKEW >10°; STAGED CONSTRUCTION**

---

**NOTES**

Transverse tension rods are to be 1/4" diameter galvanized structural rods conforming to ASTM A490 with threaded ends tensioned to 30,000 lbs. The rod shall have a washer and nut at each end. Rods, nuts, and couplers are to be galvanized.

The Contractor may use galvanized couplers to tie the transverse rods between Stage I and Stage II and tension to 30,000 lbs.

The Contractor shall verify location of recesses based on setting sequence. For waterproofing details and installation procedure, see sheet 16.

The rod shall have a washer and nut at each end. Rods, nuts, washers and 5 x 5 x 1 steel plates shall be galvanized.

Transverse ties shall be 1/4" diameter galvanized structural rods conforming to ASTM A449 with threaded ends tensioned to 30,000 lbs. The rod shall have a washer and nut at each end. Rods, nuts, washers and 5 x 5 x 1 steel plates shall be galvanized.

---

**ERECTION DIAGRAM**

**SECTION A-A**

Not to scale

---

**DETAIL C**

Not to scale

---

**DETAIL B**

Not to scale

---

**DETAIL A**

Not to scale

---

**PLAN**

Not to scale
PRESSESSED AND POST-TENSIONED CONCRETE
PRESTRESSED CONCRETE BOX BEAMS
SAMPLE ERECTION DIAGRAM; VAMC DETAILS; SKEW >10°; STAGED CONSTR.
PRESTRESSED CONCRETE INVERTED T-BEAMS

GENERAL INFORMATION:

This section provides the general practices and requirements for design and fabrication of the precast concrete inverted T-beam system. The section is developed based on the research report *Implementation of a Precast Inverted T-beam System in Virginia*, VTRC 18-R7, two existing bridges: Rte 360 over Chickahominy River and Rte 676 over Rocky Run, and the AASHTO LRFD Specifications.

The prestressed concrete inverted T-beam with tapered webs used by the Structure and Bridge Division is listed in File No. 12.07-3 along with the section properties.

Prestressed concrete inverted T-beams shall not be used on bridges with the following roadway functional classifications:

- Freeways
- Urban/Rural Principal Arterial

Prestressed concrete inverted T-beams may be used on all other roadway functional classifications with design year ADTT ≤ 200.

Asphalt overlays shall not be used with prestressed concrete inverted T-beams.

Concrete:

Prestressed Concrete used in the design of prestressed concrete inverted T-beams shall be Class A5 having a minimum 28 day compressive strength of 5000 psi. Lightweight concrete may be used in a bridge with inverted T-beams with design approval from the District Structure and Bridge Engineer.

The minimum compressive strength of concrete at release shall be 4000 psi and shall be specified in the General Notes shown on the title sheet of the plans.

Reinforcement:

All prestressed and non-prestressed reinforcement used in the fabrication and design of prestressed concrete inverted T-beams shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

Prestressing strands used in prestressed concrete inverted T-beams shall normally be designed using 0.6” diameter prestressing strands.

Limitations:

Span: Inverted T-beams are limited to simple span bridges with a maximum span length not larger than 45’.

Skew: Inverted T-beams shall not be used on a bridge with skew >10 degrees.
COMPOSITE CONCRETE DECK:

The concrete deck is assumed to act integrally with the prestressed concrete inverted T-beam sections. The cast-in-place concrete deck shall be designed to have a minimum 7 ½” thickness from the top of the inverted T-beam.

Concrete:

Concrete used in the concrete deck shall be Low Shrinkage Class A4 Modified having a minimum 28 day compressive strength of 4000 psi.

Reinforcement:

The minimum reinforcement in the concrete deck is as follows:

Two layers of #4 @ 12” in longitudinal direction;
Top layer of #4 @ 12” and bottom layer of #4 @ 6” in transverse direction.

S&B STANDARD DETAIL SHEETS AND CELL LIBRARIES:

Standards for prestressed concrete inverted T-beams are located in Part 5 of this manual along with the corresponding cell library.
SECTION PROPERTIES AND STRAND PATTERN LAYOUT

Inverted T-Beam

PRESTRESSED CONCRETE INVERTED T-BEAM 6'-0" x 18"

<table>
<thead>
<tr>
<th>Width</th>
<th>Depth</th>
<th>C.G. Top</th>
<th>C.G. Bottom</th>
<th>Net Area</th>
<th>Moment of Inertia</th>
<th>Section Modulus Top</th>
<th>Section Modulus Bottom</th>
<th>Weight @ 155pcf</th>
</tr>
</thead>
<tbody>
<tr>
<td>W (ft)</td>
<td>D (in)</td>
<td>A net (in²)</td>
<td>I (in⁴)</td>
<td>S top (in³)</td>
<td>S bot (in³)</td>
<td>(lbs/lin.ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>11</td>
<td>7</td>
<td>777</td>
<td>19461</td>
<td>1769</td>
<td>2780</td>
<td>836</td>
</tr>
</tbody>
</table>

Weight provided is for inverted T-beam section only.

All strand positions shall be on a 2" by 2" grid including any courtesy strand locations.

STRAND PATTERN LAYOUT

<table>
<thead>
<tr>
<th>Beam Size</th>
<th>Max. Number of Strands Per Row</th>
<th>Distance from Bottom of Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Row 1</td>
<td>Row 2</td>
</tr>
<tr>
<td>6'-0&quot; x 18&quot;</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Number and distances shown are for interior inverted T-beams only. For exterior solid slabs, the strand position distances should be similar. See File No. 12.07-4.
Solid Rectangular Slab:

Use precast rectangular solid slabs as exterior beams where inverted T-beams are used as interior beams in a bridge. The depth of the rectangular solid slab should be same as the depth of the inverted T-beams. The width of the exterior rectangular slab is dependent on the edge-to-edge deck width.

**PRESTRESSED CONCRETE SOLID RECTANGULAR SLAB**

X'-X” x 18”

**DRIP DETAIL**

(The drip is applied to the exterior face of rectangular slab only.)
DESIGN CONSIDERATIONS:

LIVE LOAD DISTRIBUTION FACTORS IN LRFD DESIGN AND LRFR RATING:

Inverted T-beam superstructures are not included in the common beam-slab bridges in Article 4.6.2.2 of the AASHTO LRFD Specifications.

According to the research report *Implementation of a Precast Inverted T-beam System in Virginia*, VTRC 18-R7, using Article 4.6.2.2 for adjacent box beams or voided slabs to compute the live load distribution factors for the inverted T-beams with composite concrete deck is overly conservative for shear design. The research report recommends the live load distribution factors for both moment and shear for a bridge consisting of the inverted T-beams with composite concrete deck be calculated based on assuming cast-in-place slab-type bridge system behavior.

Live load distribution factors for inverted T-beam system shall be computed using Equations 4.6.2.3-1 and 4.6.2.3-2 in the AASHTO LRFD Specifications for the cast-in-place slab-type bridge.

EXAMPLE OF LIVE LOAD DISTRIBUTION FACTOR (LL DF) COMPUTATIONS:

The following example shows the LL DF computations for interior inverted T-beams and exterior rectangular solid slabs using equivalent strip widths for slab-type bridges from Article 4.6.2.3.

**Given:**

Simple span bridge with $L = 45'$

Bridge Typical Section:

- $W_b =$ Barrier width (BPB series) = $1.667'$
- $W =$ Width edge-to-edge of deck = $24' + 2(3') + 2(1.667') = 33.334'$
- $NL =$ No. of design lanes = INT ($30' / 12'$) = 2 lanes
- $B_{int} =$ width of interior Inverted T-beams = $6.000'$ or 72"
- $N_b =$ No. of Inverted T-beams = INT ($W / B) = 33.334' / 6' = 5$
- $B_{ext} =$ width of exterior solid slabs = ($W – 6N_b) / 2 = 1.667'$ or 20"

Inverted T-beam Properties:

- $B =$ width = 72"
- $A =$ Area of PSC Inverted T-beam = $777.0 \text{ in}^2$
- $I_x =$ Moment of Inertia about x-x axis = $19461 \text{ in}^4$
- $I_y =$ Moment of Inertia about y-y axis = $185490 \text{ in}^4$
- $I_p =$ $I_x + I_y = 204951 \text{ in}^4$
- $J =$ $A^2 / (40 \times I_p) = 44460 \text{ in}^4$ [for stocky open sections]
EXAMPLE OF LIVE LOAD DISTRIBUTION FACTORS COMPUTATIONS (cont.)

Per Article C4.6.2.3, the equivalent strip width in Eq. 4.6.2.3-1 has been divided by 1.20 to account for the multiple presence effect.

For interior Inverted T-beams both moment and shear:

For one lane loaded:
- $L_1 =$ Modified span length = 45’ ($L < 60’$)
- $W_1 =$ Mod. edge-to-edge width = 30’ ($W > 30’$)
- \[ E_1 = 10.0 + 5.0(L_1W_1)^{0.5} = 193.7 \]  
  [Eq. 4.6.2.3-1]
- $DF_1 = \frac{B_{int}}{E_1} = \frac{72”}{193.7”} = 0.372$

For two or more lanes loaded:
- $L_1 =$ Modified span length = 45’ ($L < 60’$)
- $W_1 =$ Mod. edge-to-edge width = 33.334’ ($W < 60’$)
- $W =$ Physical edge-to-edge width = 33.334’
- $N_L =$ No. of design lanes as specified in Article 3.6.1.1 = 2
  
  \[ E_2 = 84.0 + 1.44(L_1W_1)^{0.5} = 139.8 < 12.0W / N_L = 200.0 \]  
  [Eq. 4.6.2.3-2]
- $DF_2 = \frac{B_{int}}{E_2} = \frac{72”}{139.8”} = 0.515$

For exterior solid slab both moment and shear:

For one lane loaded:
- $DF_1 = \frac{B_{ext}}{E_1} = \frac{20”}{193.7”} = 0.103$

For two or more lanes loaded:
- $DF_2 = \frac{B_{ext}}{E_2} = \frac{20”}{139.8”} = 0.143$

In general, for shorter and narrower bridges, the moment distribution factor for inverted T-beams computed based on the above method for slab-type bridge in Article 4.6.2.3 are larger than those computed using the methods for adjacent box beams or voided slabs from Table 4.6.2.2.1-1 in the AASHTO LRFD Specifications.
CONCRETE DECK COMPOSITE ACTION:

The experimental research and study concluded that the full composite action between the precast inverted T-beam and cast-in-place concrete deck was assured based on a full-scale beam test and adequate horizontal shear resistance can be provided solely by the adhesion and friction along the interface with surface roughness between the cast-in-place concrete and precast inverted T-beam. Extending the shear stirrups from the precast beam into the cast-in-place concrete deck may not be necessary based on the research and study.

The top surface of the bottom flanges and the tapered sides of the web shall be roughened in the longitudinal direction to a minimum amplitude of ¼". The top of the precast web shall have a transverse raked finish. Until additional research and data are available, the minimum area of interface shear reinforcement required in Article 5.7.4.2 of the AASHTO LRFD Specifications shall be provided. This minimum reinforcement requirement can be waived with a design approval from the District Structure and Bridge Engineer for cases where the horizontal shear stress is smaller than 120 psi.

DESIGN AND LOAD RATING INSTRUCTIONS:

The current versions of approved VDOT design and load rating software, Leap Bridge Concrete and AASHTOWare Bridge Rating, do not have the capacity to include all the areas of the cast-in-place concrete into computation of the properties of the composite section of the precast inverted T-beam and cast-in-place concrete deck. The area in Region 1 as shown below can be considered as cast-in-place concrete deck in computing the properties of the composite section. The concrete in Region 2 may conservatively be neglected in computing the properties of the composite section. However, the dead load from the CIP concrete in Region 2 shall be input as a line dead load for each beam.

When load rating the bridge using AASHTOWare Bridge Rating, mark the stirrups in the inverted T-beams as extending into the deck even where a design approval is obtained not to do so; otherwise the software may not rate the bridge in some cases.

NOTES TO FUTURE BRIDGE WIDENING:

Where the exterior solid rectangular slabs cannot be designed with load carrying capacity equal to the load carrying capacity of the interior inverted T-beam, the exterior solid rectangular slabs should be removed when the bridge is widened in future widening.
PRELIMINARY DESIGN CRITERIA:

The example for inverted T-beam preliminary design provided here is intended to assist the designer in selecting the concrete strength required for a particular span length. The span length is not intended to provide a final bridge design.

Preliminary design runs were performed in accordance with the AASHTO LRFD Bridge Design Specifications 7th Edition and VDOT Modifications using LEAP Bridge Concrete CONNECT Edition – Version 17.00.00.07.

Design criteria used for the development of the preliminary design include the following:

- Inverted T-beam units are designed as simply supported, typical interior unit
- Grade 270 low relaxation seven-wire strands with a 0.6” diameter are used with the standard strand 2” x 2” grid
- Concrete 28-day compressive strength of 5000 psi and release strength equal to 0.8f'_c
- Non-composite dead loads include 10 psf construction tolerance load
- Wearing surface depth 0.5” and 7” Composite Concrete Deck
- No future wearing surface load has been included in the analysis
- Composite dead loads include two F-Shape parapets (VDOT Standard BPB-3) 0.425 k/ft distributed based on tributary fraction
- Non-composite dead load of 0.550 klf for the cast-in-place concrete in the area (Region 2) between the bottom flange of inverted T-beam and deck. Dead loads from concrete deck and wearing surface are computed by LEAP Bridge Concrete.
- LRFD live load distributions factors for moment and shear have been calculated based on cast-in-place solid slab bridges using equations 4.6.2.3-1 and 4.6.2.3-2.
- Design live load: HL-93
  Legal loads: as specified under Legal Loads (a, b and c) in current IIM-S&B-86
- LEAP Bridge Concrete computes the composite section properties of the interior inverted T-beams based on 50% spacing between the adjacent beams. The composite section properties of the interior inverted T-beams next to the exterior rectangular solid beams are slightly smaller than the ones of other interior inverted T-beams due to the smaller width of the exterior rectangular solid beam.
PRELIMINARY DESIGN CRITERIA (Cont.)

- The “Approximate Method” is used in computing time dependent prestressed losses.
- “Elastic Gains” are to be neglected in the computation of prestress loss totals.

Concrete Stress Limits:

- Release w/ reinforcement:
  \[ f'_{c} (\text{psi}) = 7.5 \times \sqrt{f'_{ci}} \]
  \[ f'_{c} (\text{ksi}) = 0.24 \times \sqrt{f'_{ci}} \]
- Release tension (Top):
  \[ 3 \times \sqrt{f'_{ci}} \leq \text{max 200 psi} \]
  \[ 0.0984 \times \sqrt{f'_{ci}} \leq \text{max 0.20 ksi} \]
- Release tension (Bottom):
  \[ 0 \text{ psi}, \text{ 0 ksi} \]
- Release compression:
  \[ 0.6 \times f'_{ci} \]
  \[ 0.6 \times f'_{ci} \]
- Service tension* (Top):
  \[ 6 \times \sqrt{f'_{c}} \]
  \[ 0.19 \times \sqrt{f'_{c}} \]
- Service tension* (Bottom):
  \[ 6 \times \sqrt{f'_{c}} \]
  \[ 0.19 \times \sqrt{f'_{c}} \]
- Service compression:
  \[ 0.6 \times f'_{c} \]
  \[ 0.6 \times f'_{c} \]

*Moderate corrosion conditions assumed for top and bottom of beam

- 6” beam end extensions beyond centerline of bearing

Using the preliminary design criteria above, a maximum span length of 40’ can be achieved for class A5 5,000 psi concrete with 7 ½” cast-in-place concrete deck.
TRANSVERSE CONNECTION BETWEEN BEAMS:

Non-welded Transverse Connection details between inverted T-beams and between inverted T-beam and exterior slab are shown below.

Non-welded Transverse Connection between Inverted T-beams:

Non-welded Transverse Connection between Inverted T-beam and Solid Slab:

TRANSVERSE CONNECTION DETAIL A
Showing transverse reinforcements at bottom flange only

TRANSVERSE CONNECTION DETAIL B
END ANCHORAGE ZONE DESIGN:

AASHTO LRFD Specifications Article 5.9.4.4 requires reinforcement in end anchorage zones be provided for the splitting resistance for pretensioned precast members. The end zone reinforcing should be placed within a distance that is equal to h/4 from the end of the beam in vertical or horizontal planes depending on the geometry of the pretensioned members, strand pattern and eccentricity in the plane under consideration.

The inverted T-beam system is a new bridge system. Experimental and numerical studies have been conducted by Virginia Tech to evaluate the applicability of the current Specification provisions for the pretensioned anchorage zones. According to the studies: (1) the application of AASHTO provisions (Sixth edition and 2013 Interim Revisions) for designing vertical reinforcing steel in the pretensioned anchorage zone of the precast inverted T-beams with tapered webs are conservative; (2) no reinforcing is required in the horizontal plane to resist these bursting stresses; (3) the 4% rule presented in AASHTO for sizing reinforcing in the horizontal plane is not applicable for the bursting stresses that develop as the forces spread laterally and the confinement reinforcement designed in accordance with Article 5.9.4.4.2 can meet the requirement of the horizontal reinforcing steel.

The anchorage zone reinforcement shall be designed to meet AASHTO LRFD Specifications Article 5.9.4.4. For cases where the required reinforcement spacing results in insufficient clearance between bars, the method recommended in the research report VTRC 18-R7 may be considered.
ROUGHENED SURFACE:

Patterning the side surfaces of the tapered web and tops of the flanges in the longitudinal direction and roughening the top surface of the web in the transverse direction are required to provide adequate horizontal shear resistance between the precast Inverted T-beam and cast-in-place concrete. Similarly, for the exterior slabs, patterning the top 10" of the interior side surface in the longitudinal direction and roughening the top surface of the slab in the transverse direction are required. The patterning shall have the amplitude and spacing as shown in Standard PITN-2 in Part 5 of this manual. The roughened top surface shall be at least ¼" amplitude with distance between center of troughs of approximately 1", but not to exceed 1 ½" as shown for patterning.

PRESTRESSED CONCRETE INVERTED T-BEAM 6'-0" x 18"

(Pattern applied to the inside surface and rake finish applied to the top of slab)

PRESTRESSED CONCRETE SOLID SLAB X'-XX" x 18"

(Roughness applied to the interior side surface and rake finish applied to the top of slab)
DAPING FLANGE CORNERS

Inverted T-beam flanges should be dapped (blocked out) at beam ends to eliminate stress concentration during prestressing strand release. The block out areas also help to reduce end spalling due to beam cambers.
NOTES:

1. The bridge roadway width shown are nominal.

Concrete for the deck shall be Low Shrinkage Class A4-modified having a 28-day compressive strength of 5,000 psi.

2. Reinforcing bars in concrete overlay shall be Corrosion Resistant Reinforcing steel Class A-23.

Top surfaces of all beams shall be a clean concrete surface, free of laitance, with surface intentionally roughened to an amplitude of 1⁄2" to 1".

3. Exterior surfaces on arches to receive waterproofing membranes shall be patterned longitudinally to the amplitude shown in the PATTERNING DETAIL.

4. EPDM shall be placed over the top of the inverted T-beam web and the exterior slab shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.

5. Transversely roughened surface shall be transversely roughened to a minimum amplitude of 3⁄4", the distance between troughs or crests of pattern having a minimum compressive strength of 5,000 psi in 24 hours.

6. Reinforcement, Class ___.

7. All reinforcing bars in concrete overlay shall be Corrosion Resistant reinforcing steel Class A-23.

8. Concrete for the deck shall be Low Shrinkage Class A4-modified having a 28-day compressive strength of 4,000 psi.

9. The cost of grout, epoxy, and waterproof membrane shall be included in the cost of the prestressed member.

10. The top surfaces of bottom flange and angled sides of web for the inverted T-beam and the top 10" of the exterior side surface of the exterior slab shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.

11. The top surface of the inverted T-beam web and the exterior side shall be transversely roughened to a minimum amplitude of 3⁄4", the distance between troughs or crests of pattern having a minimum compressive strength of 5,000 psi in 24 hours.

12. Sandblasting and pre-wetted prior to grouting.

All keyway surfaces and surfaces to receive waterproofing membrane shall be cleaned of all dirt, laitance, and loose aggregate by means of sandblasting and pre-wetted prior to grouting.

The top surfaces of all beams shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.

13. Reinforcing steel, Class ___.

14. The bridge and roadway widths shown are nominal.

Concrete for the deck shall be Low Shrinkage Class A4-modified having a 28-day compressive strength of 5,000 psi.

15. Reinforcing bars in concrete overlay shall be Corrosion Resistant Reinforcing steel Class A-23.

Top surfaces of all beams shall be a clean concrete surface, free of laitance, with surface intentionally roughened to an amplitude of 1⁄2" to 1".

16. Exterior surfaces on arches to receive waterproofing membranes shall be patterned longitudinally to the amplitude shown in the PATTERNING DETAIL.

17. EPDM shall be placed over the top of the inverted T-beam web and the exterior slab shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.

18. Transversely roughened surface shall be transversely roughened to a minimum amplitude of 3⁄4", the distance between troughs or crests of pattern having a minimum compressive strength of 5,000 psi in 24 hours.

19. Reinforcement, Class ___.

20. All reinforcing bars in concrete overlay shall be Corrosion Resistant reinforcing steel Class A-23.

21. Concrete for the deck shall be Low Shrinkage Class A4-modified having a 28-day compressive strength of 4,000 psi.

22. The cost of grout, epoxy, and waterproof membrane shall be included in the cost of the prestressed member.

23. The top surfaces of bottom flange and angled sides of web for the inverted T-beam and the top 10" of the exterior side surface of the exterior slab shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.

24. The top surface of the inverted T-beam web and the exterior side shall be transversely roughened to a minimum amplitude of 3⁄4", the distance between troughs or crests of pattern having a minimum compressive strength of 5,000 psi in 24 hours.

25. Sandblasting and pre-wetted prior to grouting.

All keyway surfaces and surfaces to receive waterproofing membrane shall be cleaned of all dirt, laitance, and loose aggregate by means of sandblasting and pre-wetted prior to grouting.

The top surfaces of all beams shall be patterned longitudinally to the amplitude and frequency shown in the PATTERNING DETAIL.
PRESTRESSED CONCRETE PILE SECTIONS:

The prestressed concrete pile sections used by the Structure and Bridge Division and listed in File No. 12.08-4 are taken from the AASHTO/PCI standard prestressed concrete pile sections.

Standards for prestressed concrete piles are located in the Manual of the Structure and Bridge Division, Part 3.

- Standard BPP-1 (Carbon Steel Strands)
- Standard BPP-2 (Stainless Steel Strands)
- Standard BPP-3 (Carbon Fiber Reinforced Polymer (CFRP) Strands)

CONCRETE:

Concrete used in the design of Carbon Steel and Stainless Steel Strand prestressed concrete piles shall be Class A5 having a minimum 28 day compressive strength of 5000 psi. Concrete used in the design of CFRP Strand prestressed concrete piles shall have a minimum 28 day compressive strength of 6000 psi.

The minimum compressive strength of concrete at release shall be 3500 psi for piles with Carbon Steel or Stainless Steel Strands. The minimum compressive strength of concrete at release shall be 4200 psi for piles with CFRP strands.

PRESTRESSING STRANDS:

Bridges over tidal waters in areas east of the red highlighted routes (including the bridges on these routes) in Figure 1 on File No. 12.08-2 require the use of Stainless Steel or CRFP strands. These areas are located in the following counties and cities.

Counties: Accomack, Essex, Gloucester, Isle of Wight, James City, King and Queen, King George, Lancaster, Mathews, Middlesex, New Kent, Northampton, Northumberland, Richmond, Surry, Westmoreland and York;

Cities: Chesapeake, Hampton, Newport News, Norfolk, Poquoson, Portsmouth, Suffolk and Virginia Beach (The requirement applies to bridges owned and maintained by VDOT within these cities.).

When the use of the BPP-2 and BPP-3 standards is required:

- All piles in substructure units located within or partially within the limits of the mean high tide elevation shall use stainless steel (BPP-2) or CFRP (BPP-3) strands. Substructure units located completely outside the limits of mean high tide can use carbon steel strand (BPP-1) piles.
- When chloride content < 500 ppm, sulfate concentration < 500 ppm and pH > 5.5 in the tidal water, the BPP-1 standard can be substituted for the BPP-2 or BPP-3 standard with the approval from the District Structure and Bridge Engineer.
- The designer shall design and detail both types of piles in the bridge plans. The two alternates shall be also clearly shown on the sheet of Estimated Quantities (see Example Presenting Two Alternates for Piles in File No. 12.08-4) and in the Bid Proposal. The contractor will have the option to select either prestressed concrete piles with stainless steel strands or CFRP strands. The use of mixed strand types under one substructure unit is not allowed.
Figure 1 Limits for Use of Stainless Steel or CFRP Strands
REINFORCEMENT:

Prestressing strands shall be laid out symmetrical about a vertical and horizontal axis through the centroid of the pile cross section. Strand pattern for BPP-1 or BPP-2 may be either square or circular. Strand pattern for BPP-3 shall be circular.

Reinforcement requirement for BPP-1:

All prestressed or non-prestressed reinforcement used in the design and fabrication of prestressed concrete piles with steel strands (BPP-1) shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

Carbon Steel strands shall be 0.5” diameter strands.

Spiral ties shall be W3.5 steel wire for 12” and 14” piles, W5 steel wire for 18”, 20” and 24” piles. For Seismic Zone 2 bridges or other structures, spiral ties shall not be less than a #3 reinforcing bar or W12 wire.

Reinforcement requirement for BPP-2:

All prestressed or non-prestressed reinforcement used in the design and fabrication of prestressed concrete piles with Stainless Steel strands shall conform to the requirements specified in the Special Provision for Prestressed Concrete Piles with Stainless Steel Corrosion Resistant Reinforcement.

Stainless Steel strands shall be 0.5” diameter strands.

Spiral ties shall be W3.5 stainless steel wire for 12” and 14” piles, W5 stainless steel wire for 18”, 20” and 24” piles. For Seismic Zone 2 bridges or other structures, spiral ties shall not be less than a #3 stainless steel reinforcing bar or W12 stainless steel wire.

Reinforcement requirement for BPP-3:

All prestressed or non-prestressed reinforcement used in the design and fabrication of prestressed concrete piles with CFRP strands shall conform to the requirements specified in the Special Provision for Carbon Fiber Reinforced Prestressed Concrete Piles.

CRFP strands shall be 0.6” diameter strands.

Spiral ties shall be 0.3” CFRP bare for 12” and 14” piles, 0.4” CFRP bar for 18”, 20” and 24” piles. For Seismic Zone 2 bridges or other structures, spiral ties shall not be less than 0.4” CRFP bar at 3” pitch.
EXAMPLE PRESENTING TWO ALTERNATES FOR PILES:

### ESTIMATED QUANTITIES - SUBSTRUCTURE ONLY

<table>
<thead>
<tr>
<th></th>
<th>Concrete Class A3</th>
<th>Reinforcing Steel</th>
<th>Prestressed Concrete Piles (18')</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CY</td>
<td>LB</td>
<td>LF Administrator</td>
</tr>
<tr>
<td>Abutment A</td>
<td>Neat</td>
<td>133.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Footing</td>
<td>68.2</td>
<td>4,540</td>
</tr>
<tr>
<td>Bent I</td>
<td>48.8</td>
<td></td>
<td>303</td>
</tr>
<tr>
<td>Abutment B</td>
<td>Neat</td>
<td>136.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Footing</td>
<td>66.4</td>
<td>4,540</td>
</tr>
<tr>
<td>Total</td>
<td>452.7</td>
<td>9,080</td>
<td>303</td>
</tr>
</tbody>
</table>

Alternate 1 - with Stainless Steel Strands (BPP-2)
Alternate 2 - with Carbon Fiber Reinforced Polymer (CFRP) Strands (BPP-3)

### STRUCTURAL REQUIREMENTS:

The expected prestressing force for strand and effective prestress after losses are shown in the tables in File No. 12.08-5 thru -7.

### SECTION PROPERTIES

<table>
<thead>
<tr>
<th>Pile Size</th>
<th>AREA @ 150pcf</th>
<th>WEIGHT @ 150pcf</th>
<th>MOMENT OF INERTIA</th>
<th>SECTION MODULUS</th>
<th>RADIUS OF GYRATION</th>
<th>PERIMETER</th>
</tr>
</thead>
<tbody>
<tr>
<td>W (in)</td>
<td>AG (in²)</td>
<td>(lbs/ft)</td>
<td>(in⁴)</td>
<td>(in³)</td>
<td>(in)</td>
<td>(ft)</td>
</tr>
<tr>
<td>12</td>
<td>144</td>
<td>150</td>
<td>1728</td>
<td>288</td>
<td>3.46</td>
<td>4.00</td>
</tr>
<tr>
<td>14</td>
<td>196</td>
<td>204</td>
<td>3201</td>
<td>457</td>
<td>4.04</td>
<td>4.67</td>
</tr>
<tr>
<td>18</td>
<td>324</td>
<td>338</td>
<td>8748</td>
<td>872</td>
<td>5.20</td>
<td>6.00</td>
</tr>
<tr>
<td>20</td>
<td>400</td>
<td>417</td>
<td>13333</td>
<td>1333</td>
<td>5.77</td>
<td>6.67</td>
</tr>
<tr>
<td>24</td>
<td>576</td>
<td>600</td>
<td>27648</td>
<td>2304</td>
<td>6.93</td>
<td>8.00</td>
</tr>
</tbody>
</table>
BPP-1:

\[
\begin{align*}
\text{Pile Size} & \quad \text{Strand Pattern} & \quad \text{Total Number of Strands} & \quad \text{Diameter of Strands} & \quad \text{Strand Spacing} & \quad \text{Prestress Force per Strand} & \quad f_{cpe} \\
W \text{ (in)} & \quad \text{Square} & \quad 4 & \quad 0.5 & \quad 1 & \quad 30,980 & \quad 751 \\
12 & \quad \text{Circular} & \quad 4 & \quad - & \quad - & \quad 30,980 & \quad 751 \\
14 & \quad \text{Square} & \quad 8 & \quad 0.5 & \quad 2 & \quad 24,790 & \quad 834 \\
 & \quad \text{Circular} & \quad 6 & \quad - & \quad - & \quad 30,980 & \quad 820 \\
18 & \quad \text{Square} & \quad 12 & \quad 0.5 & \quad 3 & \quad 26,850 & \quad 835 \\
 & \quad \text{Circular} & \quad 10 & \quad - & \quad - & \quad 30,980 & \quad 827 \\
20 & \quad \text{Square} & \quad 12 & \quad 0.5 & \quad 3 & \quad 30,980 & \quad 806 \\
 & \quad \text{Circular} & \quad 12 & \quad - & \quad - & \quad 30,980 & \quad 806 \\
24 & \quad \text{Square} & \quad 16 & \quad 0.5 & \quad 4 & \quad 30,980 & \quad 751 \\
 & \quad \text{Circular} & \quad 16 & \quad - & \quad - & \quad 30,980 & \quad 751 \\
\end{align*}
\]

\( F_{\text{pbt}} \) = Prestress force per strand just prior to release after losses due to anchorage set and other factors = 0.75 \times f_{pu} \times A_{ps}, unless otherwise noted

\( A_{ps} \) = Nominal area of strands, 0.153 in\(^2\)

\( f_{pu} \) = Specified tensile strength of prestressing steel, 270 ksi

\( f_{cpe} \) = Compressive stress in concrete due to effective prestress forces only (after allowance for all prestress losses)

Note A: W3.5 wire spiral ties for 12" and 14" piles; W5 wire spiral ties for 18", 20", and 24" piles.

PILE STRAND PATTERN
## PRESTRESSED AND POST-TENSIONED CONCRETE

### PRESTRESSED CONCRETE PILES

#### STRUCTURAL REQUIREMENTS

**BPP-2:**

![Diagram of pile strand pattern](image)

*Note A: W3.5 wire spiral ties for 12" and 14" piles; W5 wire spiral ties for 18", 20" and 24" piles.*

---

### PILE STRAND PATTERN

<table>
<thead>
<tr>
<th>Pile Size W (in)</th>
<th>Strand Pattern</th>
<th>Total Number of Strands</th>
<th>Diameter of Strands (in)</th>
<th>Strand Spacing N</th>
<th>Prestress Force per Strand $F_{pbt}$ (lbs)</th>
<th>Compressive Stress in Concrete $f_{cpe}$ (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Square</td>
<td>8</td>
<td>0.5</td>
<td>2</td>
<td>19,800</td>
<td>871</td>
</tr>
<tr>
<td></td>
<td>Circular</td>
<td>6</td>
<td>0.5</td>
<td>-</td>
<td>21,600</td>
<td>747</td>
</tr>
<tr>
<td>14</td>
<td>Square</td>
<td>12</td>
<td>0.5</td>
<td>3</td>
<td>18,000</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td>Circular</td>
<td>10</td>
<td>0.5</td>
<td>-</td>
<td>21,600</td>
<td>892</td>
</tr>
<tr>
<td>18</td>
<td>Square</td>
<td>16</td>
<td>0.5</td>
<td>4</td>
<td>21,600</td>
<td>867</td>
</tr>
<tr>
<td></td>
<td>Circular</td>
<td>16</td>
<td>0.5</td>
<td>-</td>
<td>21,600</td>
<td>867</td>
</tr>
<tr>
<td>20</td>
<td>Square</td>
<td>20</td>
<td>0.5</td>
<td>5</td>
<td>21,600</td>
<td>876</td>
</tr>
<tr>
<td></td>
<td>Circular</td>
<td>18</td>
<td>0.5</td>
<td>-</td>
<td>21,600</td>
<td>800</td>
</tr>
<tr>
<td>24</td>
<td>Square</td>
<td>24</td>
<td>0.5</td>
<td>6</td>
<td>21,600</td>
<td>747</td>
</tr>
<tr>
<td></td>
<td>Circular</td>
<td>24</td>
<td>0.5</td>
<td>-</td>
<td>21,600</td>
<td>747</td>
</tr>
</tbody>
</table>

- $F_{pbt} = \text{Prestress force per strand just prior to release after losses due to anchorage set and other factors} = 0.60 \times f_{pu} \times A_{ps}$, unless otherwise noted
- $A_{ps} = \text{Nominal area of strands, 0.144 in}^2$
- $f_{pu} = \text{Specified tensile strength of prestressing steel, 250 ksi}$
- $f_{cpe} = \text{Compressive stress in concrete due to effective prestress forces only (after allowance for all prestress losses)}$
BPP-3:

0.3" CFRP spiral ties for 12" and 14" piles;
0.4" CFRP spiral ties for 18 thru 24" piles.

PILE STRAND PATTERN

<table>
<thead>
<tr>
<th>Pile Size</th>
<th>PRESTRESSING STRANDS – BPP-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>W (in)</td>
<td>Total Number of Strands</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>24</td>
<td>16</td>
</tr>
</tbody>
</table>

\[F_{\text{pbt}} = 0.55 \times f_{\text{pu}} \times A_{\text{ps}}\] is the Prestress force per strand just prior to release after losses due to anchorage set and other factors.

\[A_{\text{ps}} = \text{Nominal area of strands, 0.179 in}^2\]

\[f_{\text{pu}} = \text{Specified tensile strength of prestressing CFRP strand, 339 ksi}\]

\[f_{\text{cpe}} = \text{Compressive stress in concrete due to effective prestress forces only (after allowance for all prestress losses)}\]
ANCHORAGES AND INSERTS:

Where the ends of prestressed concrete voided slabs and box beams are constrained from lateral movement by wing haunches cast tight against the slabs/beams and buoyancy will not cause uplift of the superstructure, the ANCHOR DETAIL and ALTERNATE ANCHOR DETAIL located in the cell libraries in Part 5 of this manual are not required.

Where the ends of prestressed concrete voided slabs and box beams are not constrained or buoyancy will cause uplift of the superstructure:

1. Add both details to the standard sheets from the cell libraries contained in Part 5 of this manual.

2. All steel in the anchor assembly shown above shall be ASTM A709 Grade 36 and shall be hot dipped galvanized (except for stud shear connectors in the alternate detail).

3. H.S. bolts installed in threaded inserts shall be tightened to a snug tight condition as defined in Section 407 of the VDOT Road and Bridge Specifications. Rotational capacity test will not be required.

4. All threaded inserts shall be Dayton Superior F-62 Flared Thin Slab Ferrule NC threaded insert or an approved equal having a minimum mechanical ultimate tensile strength of 8000 lbs.

5. Designer shall verify that bridge seat reinforcement will not obstruct drilling for anchor bolts. Centerline of anchor may be shifted provided a minimum concrete cover of 2" is maintained for threaded inserts.

6. Designer shall verify that locations of threaded inserts do not interfere with the strands.
The details shown above are those for a Dayton Superior F-62 Flared Thin Slab Ferrule NC threaded insert. This threaded insert or an approved equal having a minimum mechanical ultimate tensile strength of 8000 lbs. may be used in any thin precast concrete element or for other conditions where a longer, more efficient insert cannot be used.

Sufficient depth of embedment shall be provided to develop the full ultimate strength of the threaded insert.

H.S. bolts installed in threaded inserts shall be tightened to a snug tight condition as defined in Section 407 of the VDOT Road and Bridge Specifications. Rotational capacity test will not be required.
ALTERNATE BEARING DETAILS FOR VOIED SLABS AND BOX BEAMS:

Alternate bearing details may be used for voided slabs and box beams with design approval from the District Structure and Bridge Engineer.

Plant application of approved epoxy mortar buildups at slab/beam ends for gradients in excess of 1% are difficult to fabricate. Designers shall consider designing reinforced elastomeric bearings with rotational capacity sufficient to eliminate the buildup. Designers shall consider the need for reinforced elastomeric bearings also for bridges with skews or long spans to ensure beam ends are seated properly.

Where alternate details utilize grouted anchor bolt sleeves through the solid end sections of voided slabs or box beams, Designers shall ensure the sleeves do not interfere with strand positions and shall state such in the design approval documentation.
DIAPHRAGMS:

Diaphragms for composite Bulb-T's and I-beams shall be provided in accordance with the requirements of Article 5.12.4 of the AASHTO LRFD specifications and as noted below.

End diaphragms shall be cast-in-place concrete diaphragms. For typical cast-in-place concrete end diaphragm details, see File Nos. 12.10-6 and -7.

Intermediate diaphragms shall be either steel channel or cross-frame. Use standard sheet PCBT-D1 in Part 4 of this manual for depths of 29" through 53" (standards PCBT-29, -37, -45 and -53). Use standard sheet PCBT-D2 in Part 4 of this manual for depths of 61" through 93" (standards PCBT-61, -69, -77, -85 and -93).

When utility lines are located between two lines of beams and clearance problems arise with the use of steel diaphragms, cast-in-place concrete intermediate diaphragms may be used. For typical cast-in-place concrete intermediate diaphragm details, see File Nos. 12.10-8 and -9.

CONCRETE:

Concrete used in cast-in-place concrete end and intermediate diaphragms shall be Class A4 having a minimum 28 day compressive strength of 4000 psi.

REINFORCEMENT:

All reinforcement used in cast-in-place concrete end and intermediate diaphragms shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

SPACING AND LAYOUT OF INTERMEDIATE DIAPHRAGMS:

Intermediate diaphragms are not required for spans less than 40 feet. The spacing of intermediate diaphragms for spans greater than 40 feet shall be as follows:

For spans ≤ 80 feet: at point of maximum moment.

For spans > 80 feet: equally spaced with a maximum spacing of 40 feet.

Intermediate diaphragms when required, shall be placed as follows:

For bridge skews ≤ 20°: parallel to bridge skew.

For bridge skews > 20°: normal to main bridge members.

For guidelines in laying out of intermediate diaphragms, see File Nos. 12.10-2 thru -5.
1. The details shown above are for the designer’s information only. See Introduction File No. 12.00-1.

2. The line through centers of bearings shown above also represents the center of full integral abutments.

40 ft. < SPAN LENGTH ≤ 80 ft.

SPAN LENGTH > 80 ft.
3. The lines through centers of inserts or bolts shown on previous sheet represent:
   - For steel diaphragms, the centerline locations of beam web threaded inserts or open holes for thru-bolts with respect to centerline of beam webs.
   - For cast-in-place concrete diaphragms, the centerline locations of diaphragms, beam web threaded inserts or open holes for reinforcement steel with respect to centerline of beam webs.

4. Designers shall check the proposed locations of diaphragms to insure that there are no conflicts with other superstructure or beam components.
40 ft. < SPAN LENGTH ≤ 80 ft.

SPAN LENGTH > 80 ft.

1. The details shown above are for the designer's information only. See Introduction File No. 12.00-1.

2. The line through centers of bearings shown above also represents the closure diaphragm and pier.
3. The lines through centers of inserts or bolts shown on previous sheet represent:
   - For steel diaphragms, the centerline locations of beam web threaded inserts or open holes for thru-bolts with respect to centerline of beam webs.
   - For cast-in-place concrete diaphragms, the centerline locations of diaphragms, beam web threaded inserts or open holes for reinforcement steel with respect to centerline of beam webs.

4. Designers shall check the locations of diaphragms to insure that there are no conflicts with other superstructure or beam components.

5. When laying out lines of diaphragms for end sections of beam erection diagrams, the designer shall locate lines of diaphragms so that no beam has a distance greater than 40 feet between diaphragms.

6. Where a line of diaphragms is discontinued at an exterior or interior beam, the designer shall verify that sufficient space is available between diaphragm connection plates and other superstructure or beam components to avoid conflicts during erection.

7. The use of stepped diaphragm patterns shall not be permitted.
1. The details shown above are for the designer's information only. See Introduction File No. 12.00-1.

2. DS04 series bars shown above shall be equally spaced between the beam top flanges. Spacing of bars shall not exceed 12" on centers.
3. A three piece bar detail may be used in lieu of the one piece DS04 series bar shown on the previous sheet. Minimum lap length shall be that required for a Class B tension lap splice for other than top bars (1'- 4’). Show lap length on the plans.

4. DL04 and DL06 series bars, 7/8" diameter bolts and inserts shown on the previous sheet shall be equally spaced within the beam web. Spacing of bars, bolts and inserts shall not exceed 12" on centers. Minimum lap length for DL04 and DL06 bars shall be that for a Class B tension lap splice for top bars (2'- 9’). Show lap length on the plans.

5. All threaded inserts shall be 7/8"- 9 NC threaded plain ferrule inserts suitable for thin precast concrete elements. See File No. 12.09-3.
1. The details shown above are for the designer's information only. See Introduction File No. 12.00-1.

2. Cast-in-place concrete intermediate diaphragms may be used when clearance problems arise with the use of either steel channel or cross frame diaphragms between beam lines containing utility lines.
3. DS04 series bars shown on the previous sheet shall be equally spaced between the beam top flanges. Spacings of bars shall not exceed 12” on centers.

4. A three piece bar detail may be used in lieu of the one piece DS04 series bar shown on the previous sheet. Minimum lap length shall be that required for a Class B tension lap splice for other than top bar (1’- 4”). Show lap length on the plans.

5. DL04 and DL06 series bars, 7/8” diameter bolts and inserts shown on the previous sheet shall be equally spaced within the beam web. Spacings of bars, bolts and inserts shall not exceed 12” on centers. Minimum lap length for DL04 and DL06 bars shall be that required for a Class B tension lap splice for top bars (2’- 9”). Show lap lengths on the plans.

6. All threaded inserts shall be 7/8”- 9 NC threaded plain ferrule inserts suitable for thin precast concrete elements. See File No. 12.09-3.
CONTINUITY DIAPHRAGMS FOR BULB-T'S:

This section establishes the practices and requirements for the design and detailing of closure diaphragms for simple span prestressed concrete Bulb-T sections made continuous for superimposed (composite) DL and LL+IM for the AASHTO LRFD specifications.

The design practices and reinforcement details contained in this section were established as a result of research done by Virginia Tech in Blacksburg, Virginia.

The design and detailing of closure diaphragms for simple span prestressed concrete Bulb-T's sections made continuous for composite DL and LL+IM shall be in accordance with the requirements of Article 5.12.3.3 of the AASHTO LRFD specifications as supplemented herein.

Use standard sheet PCBT-CLOS1 in Part 4 of this manual for depths of 29” thru 61” (PCBT-29 thru -61) and standard sheet PCBT-CLOS2 in Part 4 of this manual for depths of 69” thru 93” (PCBT-69 thru -93).

CONCRETE:

Concrete used in cast-in-place concrete closure diaphragms shall be Class A4 having a minimum 28 day compressive strength of 4000 psi.

REINFORCEMENT:

All reinforcement used in cast-in-place concrete closure diaphragms shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

MINIMUM AGE OF BEAM:

The minimum age of a prestressed concrete beam at time of establishment of continuity (at time closure diaphragms are cast) shall not be less than 90 days from release of strands.

When this is not practical such as in the case of emergency repairs or beams damaged during fabrication or erection, the beam shall be designed as simple span for moment and for continuous span for maximum shear/reaction using the appropriate positive moment reinforcement details shown in this section.

NEGATIVE MOMENT REINFORCEMENT:

Longitudinal reinforcement shall be provided in deck slabs over beams made continuous to resist the negative moments due to composite DL and LL+IM.

Negative moment reinforcement shall be designed in accordance with the requirements of Article 5.12.3.3.8 of the AASHTO LRFD specifications.
CONTINUITY DIAPHRAGM THICKNESS:

The closure diaphragm thickness shall be 1'-1".

PIER SEAT ELEVATIONS:

Pier seats of “arriving” and “departing” beams made continuous shall be set to the same elevation.

Where “arriving” and “departing” beams result in calculated differences in pier seat elevations, the differences shall be applied in accordance with the following guidelines:

- Difference < $\frac{1}{4}$": apply to the minimum computed bolster thickness.
- $\frac{1}{4}$" $\leq$ Difference $\leq$ $\frac{1}{2}$": apply to bearing assembly height.
- Difference $> \frac{1}{2}$": apply to pier seat elevation.

STEEL DOWELS AT FIXED SUPPORTS:

Steel dowels shall be corrosion resistant reinforcing steel, Class I. The size and number of steel dowels required shall be determined by using a nominal horizontal shear resistance (kips) per dowel = $0.47F_y A_{dowel}$ and a maximum dowel spacing of 12" between pier seats. Minimum dowel diameter shall be $\frac{3}{4}$". Details of the steel dowels and keyed construction joint shall be shown on the pier detail sheets. Dowels shall be equally spaced between pier seats. Embed dowels a minimum of 12" into pier cap.

DECK SLAB PORTION CAST MONOLITHIC WITH CLOSURE DIAPHRAGM:

A portion of the deck slab shall be cast monolithically with the closure diaphragm. The minimum width of deck slab to be cast with the diaphragm shall be 4'-0" (2'-0" on each side of pier centerline). For skew angles greater than 20°, adjust width of deck slab as necessary to ensure that this portion of the deck slab covers the entire closure diaphragm. This dimension shall be shown on the Deck Slab Concrete Placement Schedule.
POSITIVE MOMENT REINFORCEMENT DETAILS:

The positive moment reinforcement details shown in this section were developed for the Bulb-T sections using the nonprestressed reinforcement approach contained in Article 5.12.3.3.9 of the AASHTO LRFD specifications.

When beam sections other than precast concrete Bulb-T sections (PCBT-series) are made continuous for super-imposed DL and LL+Impact, the designer shall verify that the reinforcement details shown below meet the requirements of Article 5.12.3.3 of the AASHTO LRFD specifications.

For Bulb-T sections, PCBT-29 through -61, see Reinforcement Detail A below.

![Diagram of positive moment reinforcement details for Bulb-T sections]

**REINFORCEMENT DETAIL A**

Note: 4 - No. 6 hairpin bars as per research done by Virginia Tech.

![Diagram of reinforcement detail A]

**BEAM END VIEW AT CLOSURE DIAPHRAGM**
For Bulb-T sections, PCBT-69 through -93, see Reinforcement Detail B below.

**REINFORCEMENT DETAIL B**

Note: 4 - No. 6 hairpin bars with two strands bent up into closure diaphragm as per research done by Virginia Tech.

**BEAM END VIEW AT CLOSURE DIAPHRAGM**

- Bars and strands from beam in adjacent span
PRETENSIONED ANCHORAGE ZONE DESIGN:

This section establishes practices and requirements regarding the design and detailing of the pretensioned anchorage zone reinforcement for prestressed concrete Bulb-T's.

The design practices, tables and reinforcement details contained in this section were established as a result of research done by Virginia Tech in Blacksburg, Virginia to address problems with cracking at beam ends.

The practices and requirements set forth herein are intended to supersede the requirements set forth in the AASHTO LRFD specifications.

The anchorage zone as referred to in this section is the region from end of beam to 3h/4 where h is the depth of the member. For purposes of design, the anchorage zone is divided into two regions. The first region extends from end of beam to h/4 and the other region extends from h/4 to 3h/4.

In the anchorage zone region between h/4 and 3h/4, it is suggested that the designer first design for the anchorage zone reinforcement requirements set forth herein and then check against the requirements for horizontal and vertical shear. The most stringent requirement shall govern. In the region beyond 3h/4, stirrups shall be provided as required for horizontal and vertical shear.

Confinement reinforcement at beam ends shall be provided in accordance with the requirements contained in Article 5.9.4.4.2 of the AASHTO LRFD specifications.

For Anchorage Zone Reinforcement Details, see File Nos. 12.12-2 and –3.

For Anchorage Zone Design Tables, see File Nos. 12.12-4 thru –8.

BULB-T REINFORCEMENT DETAILS:

The stirrups used in the anchorage zone shall consist of a standard 180° bend, double leg stirrup with 90° standard hooks. Theoretically, two types of stirrups could be used.

- One type of stirrup extends out of the top flange of the beam to at least mid-depth of the deck slab and is used when required for horizontal shear transfer and to ensure composite action between beam and deck slab. See Detail A, File No. 12.12-3.
- The second type of stirrup does not extend above the top flange of the beam and could be used when not required for horizontal shear. See Detail B, File No. 12.12-3.

However, alternating stirrup types in the anchorage zone results in complicated details that could be misinterpreted during fabrication and not result in significant cost savings. Anchorage zone reinforcement is designed to limit crack size, number and length. As such, all stirrups in this region shall extend out of the top flange of the beam to at least mid-depth of the deck slab as shown in Detail A and be corrosion resistant in accordance with current IIM-S&B-81.

Maximum size stirrup used for anchorage zone reinforcement shall be #5.

The area of reinforcement, number and size of stirrups, and spacing required in these two regions can be obtained from the appropriate anchorage zone design table contained in this section.

The first stirrup in the region from end of beam to h/4 shall consist of a pair of bundled stirrups. Additional stirrups in the region from end of beam to h/4 may need to be bundled in order to achieve the spacing shown in the design tables.

In most cases, stirrups required in the region from h/4 to 3h/4 will not need to be bundled to achieve the spacings contained in the design tables.

Designers shall adjust location(s) of anchorage zone reinforcement to avoid conflicts with inserts, open holes and studs in insert plates.
Confinement reinforcement shall be a #4 bar shaped as shown in Details A, B and C below and spaced at 4" on centers for a distance of 1.5h from end of beam. The bar may be fabricated as a two-piece bar with a minimum 1'-4" lap.

**DETAIL A**

- BS04 series
- Anchorage zone reinforcement when required for horizontal shear. Place leg of bar on top of bottom layer of strands.
- BS04 series confinement reinforcement
- 0.6" φ strands

**DETAIL B**

- BS04 series
- Anchorage zone reinforcement when required for horizontal shear. Place leg of bar on top of bottom layer of strands.
- BS04 series confinement reinforcement
- 0.6" φ strands

(Information only – not to be used)

Reinforcement provided beyond the anchorage zone shall satisfy the requirements for vertical and horizontal shear.

Stirrups placed beyond the anchorage zone shall consist of a standard 180° bend, double leg stirrup without 90° standard hooks. See Detail C below.

**DETAIL C**

- BS04 series
- Reinforcement required for vertical and horizontal shear
- BS04 series confinement reinforcement when required outside the anchorage zone
- 0.6" φ strands
BULB-T DESIGN TABLES:

The design tables that follow are intended to assist the Designer in providing sufficient reinforcement in the end anchorage zone of a member to control beam end web cracking.

The design tables do not address the following:

- Beams with straight strands only or draped strands not raised to full height (approximately 4” to 6” below top of beam) at end of beam.
- Beams with debonded strands.
- Beams with 300 ksi strands.
- Beam sections other than precast concrete Bulb-T sections (PCBT-series).
- Spliced girders.

For beams with the above conditions, it is recommended that the Designer conduct an analysis using the strut-and-tie model to determine the appropriate stirrup reinforcement required.

To use the design tables, the Designer must first select the appropriate table based on the PCBT cross section and type of concrete (normal or lightweight) used. From the appropriate table the Designer can find the total area of required steel, number and size of stirrups, and spacing of stirrups for each of the anchorage zone regions.
### PCBT – 29

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{eqd}$ (in²)</th>
<th>Beam End to h/4</th>
<th>From h/4 to 3h/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number and Size</td>
<td>Number and spacing</td>
<td>Number and Size</td>
</tr>
<tr>
<td>≤ 14</td>
<td>3.04</td>
<td>1.58</td>
<td>4 - #4</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
<tr>
<td>≤ 18</td>
<td>3.91</td>
<td>1.99</td>
<td>5 - #4</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
<tr>
<td>≥ 20</td>
<td>4.34</td>
<td>2.17</td>
<td>6 - #4</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{eqd}$ (in²)</th>
<th>Beam End to h/4</th>
<th>From h/4 to 3h/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number and Size</td>
<td>Number and spacing</td>
<td>Number and Size</td>
</tr>
<tr>
<td>≤ 16</td>
<td>3.47</td>
<td>2.49</td>
<td>4 - #5</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
<tr>
<td>≤ 18</td>
<td>3.91</td>
<td>2.74</td>
<td>5 - #5</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
<tr>
<td>≥ 20</td>
<td>4.34</td>
<td>3.00</td>
<td>5 - #5</td>
<td>2 spa. @ 2 1/2”</td>
</tr>
</tbody>
</table>

### PCBT – 37

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{eqd}$ (in²)</th>
<th>Beam End to h/4</th>
<th>From h/4 to 3h/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number and Size</td>
<td>Number and spacing</td>
<td>Number and Size</td>
</tr>
<tr>
<td>≤ 14</td>
<td>3.04</td>
<td>1.70</td>
<td>5 - #4</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
<tr>
<td>≤ 18</td>
<td>3.91</td>
<td>2.07</td>
<td>6 - #4</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
<tr>
<td>≥ 20</td>
<td>4.34</td>
<td>2.26</td>
<td>4 - #5</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{eqd}$ (in²)</th>
<th>Beam End to h/4</th>
<th>From h/4 to 3h/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Number and Size</td>
<td>Number and spacing</td>
<td>Number and Size</td>
</tr>
<tr>
<td>≤ 16</td>
<td>3.47</td>
<td>2.48</td>
<td>4 - #5</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
<tr>
<td>≤ 20</td>
<td>4.34</td>
<td>3.08</td>
<td>5 - #5</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
<tr>
<td>≥ 22</td>
<td>4.77</td>
<td>3.34</td>
<td>6 - #5</td>
<td>2 spa. @ 3 1/2”</td>
</tr>
</tbody>
</table>
### PCBT – 45

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
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<tbody>
<tr>
<td>≤ 22</td>
<td>4.77</td>
<td>2.53</td>
<td>5 - #5</td>
<td>3 spa. @ 3”</td>
<td>2.36</td>
<td>4 - #5</td>
<td>4 spa. @ 5 1/2”</td>
</tr>
<tr>
<td>≥ 24</td>
<td>5.21</td>
<td>2.67</td>
<td>5 - #5</td>
<td>3 spa. @ 3”</td>
<td>2.49</td>
<td>5 - #5</td>
<td>5 spa. @ 4 1/2”</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 22</td>
<td>4.77</td>
<td>3.66</td>
<td>6 - #5</td>
<td>3 spa. @ 3”</td>
<td>3.42</td>
<td>6 - #5</td>
<td>6 spa. @ 3 3/4”</td>
</tr>
<tr>
<td>≤ 26</td>
<td>5.64</td>
<td>4.03</td>
<td>7 - #5</td>
<td>3 spa. @ 3”</td>
<td>3.76</td>
<td>7 - #5</td>
<td>7 spa. @ 3 1/4”</td>
</tr>
<tr>
<td>≥ 28</td>
<td>6.08</td>
<td>4.24</td>
<td>7 - #5</td>
<td>3 spa. @ 3”</td>
<td>3.96</td>
<td>7 - #5</td>
<td>7 spa. @ 3 1/4”</td>
</tr>
</tbody>
</table>

### PCBT – 53

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 26</td>
<td>5.64</td>
<td>3.04</td>
<td>5 - #5</td>
<td>3 spa. @ 3 3/4”</td>
<td>2.83</td>
<td>5 - #5</td>
<td>5 spa. @ 5 1/4”</td>
</tr>
<tr>
<td>≥ 28</td>
<td>6.08</td>
<td>3.2</td>
<td>6 - #5</td>
<td>3 spa. @ 3 3/4”</td>
<td>2.98</td>
<td>5 - #5</td>
<td>5 spa. @ 5 1/4”</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 24</td>
<td>5.21</td>
<td>4.17</td>
<td>7 - #5</td>
<td>3 spa. @ 3 3/4”</td>
<td>3.90</td>
<td>7 - #5</td>
<td>7 spa. @ 3 3/4”</td>
</tr>
<tr>
<td>≥ 26</td>
<td>5.64</td>
<td>4.4</td>
<td>8 - #5</td>
<td>3 spa. @ 3 3/4”</td>
<td>4.12</td>
<td>7 - #5</td>
<td>7 spa. @ 3 3/4”</td>
</tr>
</tbody>
</table>

### PCBT – 61

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 26</td>
<td>5.64</td>
<td>3.24</td>
<td>6 - #5</td>
<td>4 spa. @ 3 1/4”</td>
<td>3.03</td>
<td>5 - #5</td>
<td>5 spa. @ 6”</td>
</tr>
<tr>
<td>≥ 28</td>
<td>6.08</td>
<td>3.43</td>
<td>6 - #5</td>
<td>4 spa. @ 3 1/4”</td>
<td>3.20</td>
<td>6 - #5</td>
<td>6 spa. @ 5”</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in$^2$)</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req}$ (in$^2$)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 26</td>
<td>5.64</td>
<td>4.71</td>
<td>8 - #5</td>
<td>4 spa. @ 3 1/4”</td>
<td>4.39</td>
<td>8 - #5</td>
<td>8 spa. @ 3 3/4”</td>
</tr>
<tr>
<td>≥ 28</td>
<td>6.08</td>
<td>5.01</td>
<td>9 - #5</td>
<td>4 spa. @ 3 1/4”</td>
<td>4.67</td>
<td>8 - #5</td>
<td>8 spa. @ 3 3/4”</td>
</tr>
</tbody>
</table>
### PCBT – 69

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>(A_{ps} \text{ (in}^2)</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\leq 34)</td>
<td>7.38</td>
<td>3.92</td>
<td>7 - #5</td>
<td>4 spa. @ 3 3/4&quot;</td>
<td>3.65</td>
<td>6 - #5</td>
<td>6 spa. @ 5 3/4&quot;</td>
</tr>
<tr>
<td>(\geq 36)</td>
<td>7.81</td>
<td>4.02</td>
<td>7 - #5</td>
<td>4 spa. @ 3 3/4&quot;</td>
<td>3.75</td>
<td>7 - #5</td>
<td>7 spa. @ 5&quot;</td>
</tr>
</tbody>
</table>

**Lightweight Concrete – 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>(A_{ps} \text{ (in}^2)</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\leq 32)</td>
<td>6.94</td>
<td>5.51</td>
<td>9 - #5</td>
<td>4 spa. @ 3 3/4&quot;</td>
<td>5.14</td>
<td>9 - #5</td>
<td>9 spa. @ 3 3/4&quot;</td>
</tr>
<tr>
<td>(\geq 34)</td>
<td>7.38</td>
<td>5.66</td>
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<td>4 spa. @ 3 3/4&quot;</td>
<td>5.28</td>
<td>9 - #5</td>
<td>9 spa. @ 3 3/4&quot;</td>
</tr>
</tbody>
</table>

### PCBT – 77

**Normal Weight Concrete – 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>(A_{ps} \text{ (in}^2)</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
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<tbody>
<tr>
<td>(\leq 30)</td>
<td>6.51</td>
<td>3.96</td>
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<td>5 spa. @ 3 1/2&quot;</td>
<td>3.70</td>
<td>6 - #5</td>
<td>6 spa. @ 6 1/2&quot;</td>
</tr>
<tr>
<td>(\leq 34)</td>
<td>7.38</td>
<td>4.25</td>
<td>7 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>3.97</td>
<td>7 - #5</td>
<td>7 spa. @ 5 1/2&quot;</td>
</tr>
<tr>
<td>(\leq 38)</td>
<td>8.25</td>
<td>4.55</td>
<td>8 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>4.25</td>
<td>7 - #5</td>
<td>7 spa. @ 5 1/2&quot;</td>
</tr>
<tr>
<td>(\geq 40)</td>
<td>8.68</td>
<td>4.69</td>
<td>8 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>4.37</td>
<td>8 - #5</td>
<td>8 spa. @ 4 3/4&quot;</td>
</tr>
</tbody>
</table>

**Lightweight Concrete - 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>(A_{ps} \text{ (in}^2)</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>(A_{req} \text{ (in}^2)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\leq 28)</td>
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<td>5.40</td>
<td>9 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>5.04</td>
<td>9 - #5</td>
<td>9 spa. @ 4 1/4&quot;</td>
</tr>
<tr>
<td>(\leq 34)</td>
<td>7.38</td>
<td>6.13</td>
<td>10 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>5.72</td>
<td>10 - #5</td>
<td>10 spa. @ 3 3/4&quot;</td>
</tr>
<tr>
<td>(\geq 36)</td>
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<td>6.36</td>
<td>11 - #5</td>
<td>5 spa. @ 3 1/2&quot;</td>
<td>5.93</td>
<td>10 - #5</td>
<td>10 spa. @ 3 3/4&quot;</td>
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### PCBT – 85

**Normal Weight Concrete - 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
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<tbody>
<tr>
<td>$\leq 32$</td>
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<td>4.27</td>
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<td>5 spa. @ 3 3/4&quot;</td>
<td>3.99</td>
<td>7 - #5</td>
<td>7 spa. @ 6&quot;</td>
</tr>
<tr>
<td>$\leq 38$</td>
<td>8.25</td>
<td>4.84</td>
<td>8 - #5</td>
<td>5 spa. @ 3 3/4&quot;</td>
<td>4.51</td>
<td>8 - #5</td>
<td>8 spa. @ 5 1/4&quot;</td>
</tr>
<tr>
<td>$\geq 44$</td>
<td>9.55</td>
<td>5.09</td>
<td>9 - #5</td>
<td>5 spa. @ 3 3/4&quot;</td>
<td>4.76</td>
<td>8 - #5</td>
<td>8 spa. @ 5 1/4&quot;</td>
</tr>
</tbody>
</table>

**Lightweight Concrete - 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
</tr>
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<tr>
<td>$\leq 30$</td>
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<td>5.73</td>
<td>10 - #5</td>
<td>10 spa. @ 4 1/4&quot;</td>
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<tr>
<td>$\leq 34$</td>
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<td>6.75</td>
<td>11 - #5</td>
<td>5 spa. @ 3 3/4&quot;</td>
<td>6.30</td>
<td>11 - #5</td>
<td>11 spa. @ 3 3/4&quot;</td>
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<tr>
<td>$\geq 40$</td>
<td>8.68</td>
<td>7.28</td>
<td>12 - #5</td>
<td>5 spa. @ 3 3/4&quot;</td>
<td>6.80</td>
<td>11 - #5</td>
<td>11 spa. @ 3 3/4&quot;</td>
</tr>
</tbody>
</table>

### PCBT – 93

**Normal Weight Concrete - 0.6” diameter strands - Stirrup Stress = 18 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
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<tr>
<td>$\leq 34$</td>
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<td>6 spa. @ 3 1/2&quot;</td>
<td>4.45</td>
<td>8 - #5</td>
<td>8 spa. @ 5 3/4&quot;</td>
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<tr>
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<td>5.21</td>
<td>9 - #5</td>
<td>6 spa. @ 3 1/2&quot;</td>
<td>4.86</td>
<td>8 - #5</td>
<td>8 spa. @ 5 3/4&quot;</td>
</tr>
<tr>
<td>$\leq 44$</td>
<td>9.55</td>
<td>5.56</td>
<td>9 - #5</td>
<td>6 spa. @ 3 1/2&quot;</td>
<td>5.19</td>
<td>9 - #5</td>
<td>9 spa. @ 5&quot;</td>
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<tr>
<td>$\geq 46$</td>
<td>9.98</td>
<td>5.67</td>
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<td>6 spa. @ 3 1/2&quot;</td>
<td>5.29</td>
<td>9 - #5</td>
<td>9 spa. @ 5&quot;</td>
</tr>
</tbody>
</table>

**Lightweight Concrete - 0.6” diameter strands - Stirrup Stress = 12 ksi**

<table>
<thead>
<tr>
<th>Number of Strands</th>
<th>$A_{ps}$ (in²)</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
<th>$A_{req'}$ (in²)</th>
<th>Number and Size</th>
<th>Number and spacing</th>
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<tbody>
<tr>
<td>$\leq 28$</td>
<td>6.08</td>
<td>6.66</td>
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<td>6 spa. @ 3 1/2&quot;</td>
<td>6.22</td>
<td>11 - #5</td>
<td>11 spa. @ 4 1/4&quot;</td>
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<tr>
<td>$\leq 34$</td>
<td>7.38</td>
<td>7.25</td>
<td>12 - #5</td>
<td>6 spa. @ 3 1/2&quot;</td>
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<td>11 - #5</td>
<td>11 spa. @ 4 1/4&quot;</td>
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<tr>
<td>$\leq 38$</td>
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<td>7.77</td>
<td>13 - #5</td>
<td>6 spa. @ 3 1/2&quot;</td>
<td>7.24</td>
<td>12 - #5</td>
<td>12 spa. @ 3 3/4&quot;</td>
</tr>
<tr>
<td>$\geq 40$</td>
<td>8.68</td>
<td>8.01</td>
<td>14 - #5</td>
<td>6 spa. @ 3 1/2&quot;</td>
<td>7.48</td>
<td>13 - #5</td>
<td>13 spa. @ 3 1/2&quot;</td>
</tr>
</tbody>
</table>
INSTRUCTION FOR USE OF CELLS FOR STANDARD PCBT-MISC2:

Two complete sets of cells are developed for use with Standard PCBT-MISC2 and are found in the PCB.CEL library. Each cell set consists of series for beam end details with 0 degree skew, left clip, left skew, right clip and right skew for use with closure diaphragms (when applicable), end diaphragms, full integral abutments and semi-integral abutments.

Two sets are necessary as the number of spaces in the first spacing from end of beam to h/4 may be even or odd and BS0401 bars will typically be required at every other stirrup spacing. Designers shall ensure this distance does not exceed maximum BS0401 spacing required by design.

The two sets are setup for even number of spaces for both the first and second (h/4 to 3h/4) spacing and odd number of spaces for both the first and second (h/4 to 3h/4) spacing. Where the second spacing differs from the first (i.e., even/odd or odd/even), it is suggested that an extra space be added to the second spacing to preclude having to revise the cell details.

As an example, for the sample plan set in Section 13 of this chapter, the 53” bulb-T has 38 strands. Referring to the PCBT-53 anchorage zone design table for normal weight concrete, 3 spaces (odd number of spaces) at 3 ¾” is required from the beam end to h/4 and 5 spaces (odd number of spaces) at 5 ¼” from h/4 to 3h/4. Therefore, the odd cell series can be used without modification. Say the spacing between h/4 and 3h/4 was 6 spaces at 4 ½”. The odd cell series could still be used without modification only if the Designer increased the number of spaces from 6 to 7 spaces at 4 ½”.

Bundled Bars:

The cells are detailed assuming the first three spaces require bundled bars in order to achieve the required reinforcement and spacing shown in the design tables. The first stirrup in the region from end of beam to h/4 shall always consist of a pair of bundled stirrup bars. Where the number of additional stirrup bars in the region from the end of beam to h/4 required is different from the number provided by the cells, modify the number of arrowheads and leader lines accordingly.

Coordination Between Prestressed Concrete Bulb-T and MISC2 Standard:

Where beam extensions on the left and right sides beyond the referenced “L” dimension are not equal, additional spaces may need to be added to one of the beam ends on the MISC2 sheet.

As an example, for the sample plan set in Section 13 of this chapter, the distance “E” from the insert plate centerline to the end of the beam at the semi-integral end is 1’-10”. The distance “D” from the insert plate centerline to the end of the beam at the closure diaphragm is 11 ½”. In order for the spacing of the BS0401 and BS0403 bars shown on the prestressed concrete bulb-T standard to be roughly symmetric, additional spaces must be added to the semi-integral end. In this particular case, two additional spaces at 5 ¼” were added to the MISC2 detail at the semi-integral end totaling 10 ¾”, so the interior BS0401 and BS0403 bars are actually symmetric about midspan (i.e., 22” – 11 ¼” = 10 ½”).

The BS0401 and BS0403 bars can be roughly symmetrical (i.e., not exactly symmetrical) about midspan if the required maximum spacing for both bars is not exceeded throughout the beam and across the un-dimensioned space at midspan.
Special Details:

Special details will be required for beam ends with left or right skew beyond a non-determined skew based on spacing of reinforcement. In these cases, the Designer should independently detail the beam ends to scale to show the necessary details. The sketch below depicting the top flange and web is provided to portray issues to be resolved and not a working layout.

Similar issues affect the bottom flange confinement bar positions beyond a non-determined skew. Placing a two piece confinement bar (i.e., lapped) is problematic and most Fabricators prefer using a single bar. Designers should determine the distance over which bars need to be splayed to maintain the proper average spacing and not violate minimum clearance between bars and whether one or more bar designations needs to be specified. Shear stud spacing where insert plates are used should also be investigated.
ERECTION DIAGRAM SHEET:

This section of the chapter establishes the practices/requirements necessary for the completion of the erection diagram sheet for a plan assembly. Included are sample erection diagram sheets with a checklist for completing these sheets.

It is not the intent of the sample erection diagram sheets and checklist contained in this section to show how to lay out the superstructure of a bridge.

A typical project will normally have a single erection diagram sheet which will include notes. Space permitting, other details pertaining to the erection diagram or prestressed concrete member may be shown on this sheet. In all cases, the erection diagram sheet shall contain all of the items shown in this section. Information placed in blocks on the sample erection diagram sheets is for designer’s information only and are not to be placed on the erection diagram sheet.

For major projects or long structures, the erection diagram sheet may have to be extended to additional sheets to adequately show the complete structure. For structures with repetitive spans, only one erection diagram need be drawn for each typical unit. Designation of typical units shall be indicated on the title sheet (plan view).

The practices for the completion of interior sheets contained in Chapter 4 shall be adhered to.
For prestressed concrete beam details, see sheet 13.
For intermediate diaphragm details, see sheet 14.
For end and closure diaphragm details, see sheet 14.

Prestressed and Post-Tensioned Concrete
Sample Erection Diagram

Design:
Non-integral Abutments
3-spn continuous, 1-simple span
10'-0" Deck = 20º
Steel Intermediate Diaphragms
Notes:
for prestressed concrete beam details, see sheet 13.
for intermediate diaphragm details, see sheet 14.
for end and closure diaphragm details, see sheet 14.
for water line attachment details, see sheet 20.

Design:
Full Integral Abutments
2-span continuous
Shear = 20º
Concrete Intermediate diaphragms
Utility waterline

PRESTRESSED AND POST-TENSIONED CONCRETE
SAMPLE ERECTION DIAGRAM
For prestressed concrete beam details, see sheet 13.
For intermediate diaphragm details, see sheet 14.
For end and closure diaphragm details, see sheet 14.
Structural Engineer: Richmond, VA
VDOT S&B Division

1'-7" 9'-2" 9'-2" 9'-2" 7'-2" 2'-0"
3 spa @ 40'-0" = 120'-0"

L Pier 1

1'-6"

107'-0"
3 spa @ 34'-8" = 104'-0"

Notes:
For prestressed concrete beam details, see sheet 13.
For intermediate diaphragm details, see sheet 14.

PRESTRESSED AND POST-TENSIONED CONCRETE
SAMPLE ERECTION DIAGRAM

ERECITION DIAGRAM - SPAN a

ERECITION DIAGRAM - UNIT A
Notes:
- For prestressed concrete beam details, see sheet 13.
- For intermediate diaphragm details, see sheet 14.
- For end and closure diaphragm details, see sheet 14.
- For other attachment details, see sheet 20.

Design:
- Full integral abutments
- Super continuous beams parallel to common chord
- Span = 20'
- Steel intermediate diaphragms

PRESTRESSED AND POST-TENSIONED CONCRETE
SAMPLE ERECTION DIAGRAM
CURVED BRIDGE LAYOUT ON COMMON CHORD

ERECTION DIAGRAM
PRESTRESSED AND POST-TENSIONED CONCRETE
SAMPLE ERECTION DIAGRAM
CURVED BRIDGE LAYOUT ON SPAN CHORDS

ERECTION DIAGRAM

Notes:
For prestressed concrete beam details, see sheet 13.
For intermediate diaphragm details, see sheet 14.
For end and closure diaphragm details, see sheet 14.

Design:
Non-Integral Abutments
Support continuous
Skew = 20°
Steel Intermediate diaphragms
Beams parallel to span chord

Commonwealth of Virginia
Department of Transportation
Structure and Bridge Division
ERECION DIAGRAM

PRESTRESSED AND POST-TENSIONED CONCRETE
SAMPLE ERECTION DIAGRAM
CURVED BRIDGE LAYOUT ON SPAN CHORDS
CHECK LIST FOR ERECTION DIAGRAM SHEET:

1. Erection diagrams shall be drawn to a scale of sufficient size to fit the full size sheet and still be legible when reduced to half-size.

2. Show skew angle(s) if applicable. Skew angle shall be as shown on the title sheet. Skew angles for curved bridge layout on span chords are angles between face of backwalls/end of slabs or \( \ell \) of pier(s)/bent(s) with a radial line through intersections of route \( \ell \) / \( \overline{\ell} \) and face of backwalls/end of slabs or \( \ell \) of pier(s)/bent(s).

3. Show and label \( \ell / \overline{\ell} \) of bridge. This designation shall match that shown on the title sheet. Do not include the word proposed.

4. Show and label \( \ell \) piers(s)/bent(s). Piers/bents shall be designated from left to right using consecutive numbers when more than one pier/bent exists, e.g., \( \ell \) Pier 1/ Bent 1. Provide station.

5. Label spans from left to right using lower case designators, e.g., Span a, Span b.

6. Label beams/girders from top to bottom using numbers, e.g., Beam 1, Beam 2.

7. Locate the \( \ell \) of all utilities supported by the bridge. Provide the number, size of conduits and name of utility utilizing the conduit(s). When water, gas or other similar systems are located on the bridge, the diameter of pipe should also be shown. Utilities shall preferably be located between an exterior beam/girder and the first interior beam/girder unless otherwise directed by the utility company. Gas lines shall be located between an exterior beam/girder and the first interior beam/girder.

8. Dimension span length(s) along the route \( \ell / \overline{\ell} \). This is the distance between the face of backwall/end of slab and the \( \ell \) of pier/bent, \( \ell \) pier/bent to \( \ell \) pier/bent, and \( \ell \) of pier/bent to face of backwall/end of slab.

9. Show beam/girder spacings. Dimensions shall be normal to the \( \ell \) of beams/girders for both straight and skewed bridges. Dimension the location of the first beam/girder on each side of the route \( \ell / \overline{\ell} \) of the bridge.

10. Show and label location of line(s) through centers of inserts or bolts for intermediate steel diaphragms or \( \ell \) of intermediate concrete diaphragms.

11. For full integral abutments, show and label Line thru center of piles and \( \ell \) of end diaphragms/piers (if applicable). Dimension location from \( \ell \) of pier at piers along the route \( \ell / \overline{\ell} \). Provide station for abutments.

12. For other abutments and pier(s)/bent(s), show and label lines thru center of bearings and \( \ell \) of end diaphragms/piers (if applicable). Dimension location from \( \ell \) of pier at piers along the route \( \ell / \overline{\ell} \). Provide station for abutments.

13. Show and label common chord for curved bridges using layout on common chord. Common chords are chords between the intersections of route \( \ell / \overline{\ell} \) with Line thru center of bearings/piles slab at abutments. Beams are laid out parallel to this chord.
Show and label span chords for curved bridges using layout on span chords. Span chords are chords between the intersections of route L/L with Line thru center of bearings/piles at abutments or L piers/bents. Dimension span chord lengths. Beams are laid out parallel to span chords.

Show angle between chords and lines thru center of bearings/piles at abutments or L Pier/Bents.

Provide North Arrow.

For an erection diagram sheet showing only a single span or multi-span erection diagram, the title for the erection diagram shall read:

ERECTION DIAGRAM

and the title in the title block shall read:

ERECTION DIAGRAM

Repetitive span units shall be labeled using upper case designators, e.g., UNIT A, UNIT B. For an erection diagram sheet showing a repetitive span erection diagram along with other span erection diagrams, the title for the repetitive span unit erection diagram shall read:

ERECTION DIAGRAM - UNIT A

and the title for other span erection diagram shall read:

ERECTION DIAGRAM - SPAN a

and the title in the title block shall read:

ERECTION DIAGRAMS
SPAN a AND UNIT A

For instructions on completing and locating the notes, see File No. 04.03.

For instructions on completing the title block, see File Nos. 04.02-1 and -2.

For instructions on completing the project block, see File No. 04.01.

For instructions on completing this portion of sheet, see File No. 01.01-7.

For instructions on completing the block for sealing, signing and dating plan assembly sheets, see File Nos. 01.16-1 thru -7.
SAMPLE PLAN ASSEMBLY:

This section of the chapter establishes the general practices/requirements necessary for the completion of a plan assembly for a typical superstructure containing prestressed concrete members. Included are sample plan sheets necessary for prestressed concrete bulb-T spans continuous for live load.

It is not the intent of the sample plan sheets contained in this section to show practices and requirements for the design of the superstructure of a bridge. The sample plan sheets shown in this section are intended only to provide the Designer with the necessary detail requirements for a complete bridge plan assembly.

For specific requirements and guidelines for completing plan sheets, refer to the appropriate sections of this chapter and notes to designers contained in Parts 3 through 5 of this manual.

The practices for the completion of interior sheets and standard sheets contained in Chapter 4 shall be adhered to.

S&B STANDARD SHEETS AND CELL LIBRARIES:

See Introduction File No. 12.00-1.
For prestressed concrete beam details, see sheet 10.
For intermediate diaphragm details, see sheet 13.
For closure diaphragm details, see sheet 14.
For integral backwall details, see sheet 15.

Notes:
- Scale: '" = 1'-0" unless otherwise shown
- Not to scale

PRESTRESSED AND POST-TENSIONED CONCRETE SAMPLE PLAN ASSEMBLY
ERECITION DIAGRAM AND TOP OF SLAB ELEVATIONS SHEET
Prestressed and Post-Tensioned Concrete Sample Plan Assembly
Miscellaneous Beam Details Sheet

Notes:
For beam details and notes, see sheet 10.
BC series bars may be shifted as directed by the Engineer to clear inserts, open holes and studs in insert plates.

AT SEMI-INTEGRAL ABUTMENT

AT CLOSURE DIAPHRAGM

TOP FLANGE AND WEB REINFORCEMENT END DETAILS

See beam sheet for position of BC0602 bars

1 bearing and insert plate

1 bearing and insert plate

See beam sheet for position of BC0603 bars

AT SEMI-INTEGRAL ABUTMENT

AT CLOSURE DIAPHRAGM

BOTTOM FLANGE REINFORCEMENT END DETAILS

See beam sheet for position of BC0603 bars

1 bearing and insert plate

1 bearing and insert plate

See beam sheet for position of BC0602 bars

END VIEW AT INTEGRAL BACKWALL

Scale: 1" = 1'-0"

Location of 1/2" @ holes

AT INTEGRAL BACKWALL

3/4" typ.

3/4" typ.

3/4" typ.

1/2" @ open holes

1/2" non-rigid tubing

Notes:
Indicates bundled bars at each location (e.g., 2 arrowsheads, first two locations)

Indicates bundled bars at each location (e.g., 2 arrowsheads, first two locations)
PART TRANSVERSE SECTION

Use Detail A at exterior beams where line of diaphragms is continuous across the structure.
Use Detail B at interior beams where line is discontinued at interior beam. Use Detail B at exterior beams and interior beams where line of diaphragms is continuous across the structure.

DIMENSION TABLE

<table>
<thead>
<tr>
<th>BEAM TYPE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>CHANNEL SIZE</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6x20.8</td>
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</table>

Notes:
- All structural steel shall be ASTM A36.
- All bolts shall be 5/8"-11 US. bolts, ASTM A325.
- All bolts used for steel-to-steel connections shall be tightened in accordance with Section 407 of the Specifications.
- All bolts used in threaded inserts shall be tightened to a snug tight condition. Rotational capacity test is not required.
- Diaphragm materials including bolts, nuts and washers shall be galvanized.
- All threaded inserts shall be 5/8"-9 NC threaded plain ferrule inserts suitable for thin precast concrete elements having a minimum ultimate tensile mechanical tensile strength of 50000 pounds.
- A 3/8" bent plate may be used in lieu of the L 6 x 6 x 1/2 connector plate shown for skew angles less than or equal to 20 degrees. The 3/8" bent plate shall be shop bent to conform with the line of diaphragms.
- All diaphragms shall be included in the contract unit price for prestressed concrete members.

Notes:
- See erection diagram for diaphragms.
- All diaphragm materials including bolts, nuts and washers shall be galvanized.
- All threaded inserts shall be 5/8"-9 NC threaded plain ferrule inserts suitable for thin precast concrete elements having a minimum ultimate tensile mechanical tensile strength of 50000 pounds.
- All bolts shall be 5/8"-11 US. bolts, ASTM A325.
- All bolts used for steel-to-steel connections shall be tightened in accordance with Section 407 of the Specifications.
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- All diaphragms shall be included in the contract unit price for prestressed concrete members.

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**Structure and Bridge Division**

**Commonwealth of Virginia**

**Department of Transportation**

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**Date Designed:**

**Drawn:**

**Checked:**

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**ROUTE NO.**

**FEDERAL AID NO.**

**PROJECT NO.**

**STATE NO.**

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**GROUP**

**CLASS**

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**S&B DIVISION**
PART SECTION CLOSURE DIAPHRAGM AT FIXED SUPPORTS

SECTION A-A

SECTION B-B

SECTION C-C

SECTION D-D

Notes:
1. This portion of the slab shall be cast with the closure diaphragm.
2. For shallower beams at the Contractor's option, reinforcing bars DS0402 and DS0403 may be detailed as a one piece bar.
3. For location and details of dowels and construction joints, see sheet 6.
4. For details of bearing assemblies, see sheet 6.
5. For beam details, see sheets 10, 11 and 12.
6. Two rows of plain and preformed joint filler shall be included in the cost of superstructure concrete.
CHECK LIST FOR SAMPLE PLAN ASSEMBLY:

1. Show PLAN view of beam. End detail(s) shown in the PLAN are for 0° skew. Modify both flange and reinforcement details for skews > 0° and/or other end conditions using appropriate details in cell library.

2. Show SECTION ON CENTERLINE of beam. Complete reinforcement details for beam shown in the SECTION ON CENTERLINE. Modify beam end(s) as required for skews > 0° and/or other end conditions using appropriate details in cell library.

3. Show TYPICAL BEAM SECTION with dimensions.

4. Show TYPICAL BOTTOM FLANGE EDGE DETAIL. The detail shown is for distances from edge of insert plate to end of beam greater than 6". For other situations, replace the existing detail with the appropriate detail in cell library.

5. Show typical beam END VIEW with reinforcement details and strand pattern.

6. Show typical beam SECTION A-A near midspan complete with reinforcement details and strand pattern.

7. Show and complete DATA AND DIMENSION TABLE.

8. Show DEAD LOAD DEFLECTION DIAGRAM. Diagram shown is for a straight gradient. For other situations, show appropriate shape (hump or sag) on the diagram using appropriate detail in cell library. Add slab thickness. See File No. 12.02-4.


10. Show REINFORCING STEEL SCHEDULE. Complete dimensioning, total numbers and lengths of rebars, and pin diameters in schedule.

11. Show Notes as required. Add appropriate sheet numbers. For instructions on completing the notes, see File No. 04.03.


13. Show and complete TOP OF SLAB ELEVATIONS ALONG C OF BEAM. Place on sheet with Erection Diagram when space permits. See File No. 12.02-5.

14. Miscellaneous required detail(s) may be shown on this sheet when space allows.

15. Show and complete the TOP FLANGE AND WEB REINFORCEMENT END DETAILS and BOTTOM FLANGE REINFORCEMENT END DETAILS. The details shown are for a 0° skew with a semi-integral abutment on the left and closure diaphragm on the right. Show the appropriate details for skew greater than 0° and/or other end conditions using the appropriate details in cell library.
Include the appropriate standard steel intermediate diaphragm details sheet.

Complete the reinforcement details for stirrup reinforcement shown in the part sections of closure diaphragm. Where lapping DL06 bars is not necessary, remove the horizontal laps shown in the part sections of closure diaphragms and change DL0607 callout to DL0606 in part sections of closure diaphragms, Section A-A and Section C-C.

Show PLAN VIEW OF CLOSURE DIAPHRAGM. Plan view of closure diaphragm shown is for 0° skew. Show the appropriate detail for skew greater than 0° using the appropriate detail in cell library.

For instructions on completing the title block, see File No. 04.04-2.

For instructions on completing the project block, see File No. 04.01.

For instructions on completing this portion of sheet, see File No. 04.04-3.

For instructions on completing the block for sealing, signing and dating plan assembly sheets, see File Nos. 01.16-1 thru -7.
CONTINUITY DIAPHRAGMS FOR I-BEAMS:

This section establishes the practices and requirements for the design and detailing of closure diaphragms for simple span prestressed concrete I-Beam sections made continuous for super-imposed (composite) DL and LL+IM for the AASHTO LRFD specifications.

The design and detailing of closure diaphragms for simple span prestressed concrete I-Beam sections made continuous for composite DL and LL+IM shall be in accordance with the requirements of Article 5.12.3.3 of the AASHTO LRFD specifications as supplemented herein.

For typical positive moment closure diaphragm details, see File Nos. 12.15-3 thru -9.

CONCRETE:

Concrete used in cast-in-place concrete closure diaphragms shall be Class A4 having a minimum 28 day compressive strength of 4000 psi.

REINFORCEMENT:

All reinforcement used in cast-in-place concrete closure diaphragms shall conform to the requirements contained in File Nos. 12.01-1 and -2 and as specified below.

MINIMUM AGE OF BEAM:

The minimum age of a precast, prestressed concrete beam at time of establishment of continuity (at time closure diaphragms are cast) shall not be less than 90 days from release of strands.

When this is not practical, the positive moment connection shall be designed in accordance with the procedures outlined in the August 1969 PCA Engineering Bulletin “Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders”. For such cases the following shall also apply:

- In using this procedure, a reduction in the simple span positive moment due to composite DL and LL + Impact may be taken for the design of the beam within the span.
- Minimum non-prestressed positive moment reinforcement shall be 4 - #8 rebars or an equivalent area of steel.
- Minimum embedment length of non-prestressed positive moment reinforcement shall be 50 times the strand diameter plus the development length in tension for the deformed bar used. In no case shall all positive moment reinforcement bars be terminated at the same location.
In lieu of non-prestressed positive moment connection reinforcement, 1/2" diameter prestressing strands may be used. When considering a service life up to two million cycles of maximum loading, 1/2" strands may be designed at a working stress ≤ 0.15f′s. Strands shall be embedded into the closure diaphragm a minimum of 2'-7” from end of beam. Pin diameter for bending 1/2" diameter strands up into the closure diaphragm shall be 3/4”.

CONTINUITY DIAPHRAGM THICKNESS:

The closure diaphragm thickness shall be 1'-1”.

NEGATIVE MOMENT REINFORCEMENT:

Longitudinal reinforcement shall be provided in deck slabs over beams made continuous to resist the negative moments due to composite DL and LL+I.

Negative moment reinforcement shall be designed in accordance with the requirements of Article 5.12.3.3.8 of the AASHTO LRFD specifications.

PIER SEAT ELEVATIONS:

Pier seats of “arriving” and “departing” beams made continuous shall be set to the same elevation.

Where “arriving” and “departing” beams result in calculated differences in pier seat elevations, the differences shall be applied in accordance with the following guidelines:

- Difference < 1/4": apply to the minimum computed bolster thickness.
- 1/4" ≤ Difference ≤ 1/2": apply to bearing assembly height.
- Difference > 1/2": apply to pier seat elevation.
POSITIVE MOMENT CLOSURE DIAPHRAGM DETAILS:

1. The details shown above and in File Nos. 12.15-4 and -5 are for the designer's information only. See Introduction File No. 12.00-1.

2. Deck slab reinforcement not shown for purposes of clarity.

3. For Sections A - A and B - B, see File Nos. 12.15-4 and -5.

4. DS04 series bars shown above shall be equally spaced between the beam top flanges. Spacing shall not exceed 12" on centers.

5. A three piece bar detail may be used in lieu of the one piece DS04 series bar shown above. Minimum lap length shall be that required for a Class B tension lap splice for other than top bars (1'- 4"). Show lap length on the plans.

6. DL06 series bars shown above shall be equally spaced between the BC05 series bars. Spacings of bars shall not exceed 12" on centers. Minimum lap length when required, for DL06 series bars shall be that required for a Class B tension lap splice for top bars (2'- 9"). Show lap length on the plans.
7. Minimum lap length for BC05 and BL05 series bars shall be that required for a Class B tension lap splice for top bars (2'- 4”). Show lap length on the plans.

8. The 3/4” diameter plain steel dowels shall conform to the requirements of ASTM A36. The size and number of steel dowels required shall be determined by using a nominal horizontal shear resistance (kips) per dowel = 0.47FyA_dowel. When in the judgement of the designer a more detailed design procedure is needed, the provisions contained in Article 5.7.4 of the AASHTO LRFD specifications may be used. Minimum size and number shall be four 3/4” diameter dowels between pier seats. Details of the 3/4” diameter steel dowels and keyed construction joint shall be shown on the pier detail sheets. Dowels shall be equally spaced between pier seats. Embed dowels 12” into pier cap.

9. This portion of the deck slab shall be cast prior to the casting of the closure diaphragm.

10. This portion of the deck slab shall be cast monolithically with the closure diaphragm. Minimum width of deck slab to be cast with the diaphragm shall be 4'- 0” (2'- 0” on each side of pier centerline). For skew angles greater than 20°, adjust width of deck slab as necessary to ensure that this portion of the deck slab covers the entire closure diaphragm. This dimension shall be shown on the Deck Slab Concrete Placement Schedule.

11. For plan view of closure diaphragm, see File No. 12.15-9.

12. For details of bearing assemblies, see standard BBD-8 in Part 3 of this manual.

For location of section cuts and notes, see File No. 12.15-3 and above.
For location of section cuts and notes, see File Nos. 12.15-3 and - 4.
1. The details shown above and in File Nos. 12.15-7 and -8 are for the designer's information only. See Introduction File No. 12.00-1.

2. Deck slab reinforcement not shown for purposes of clarity.

3. For Sections C - C and D - D, see File No. 12.15-7 and -8.

4. DS04 series bars shown above shall be equally spaced between the beam top flanges. Spacing shall not exceed 12" on centers.

5. A three piece bar detail may be used in lieu of the one piece DS04 series bar shown above. Minimum lap length shall be that required for a Class B tension lap splice for other than top bars (1'- 4"). Show lap length on the plans.

6. DL06 series bars shown above shall be equally spaced between the BC05 series bars. Spacing of bars shall not exceed 12" on centers. Minimum lap length when required, for DL06 series bars shall be that required for a Class B tension lap splice for top bars (2'- 9"). Show lap length on the plans.

7. Minimum lap length for BC05 and BL05 series bars shall be that required for a Class B tension lap splice for top bars (2'-4"). Show lap length on the plans.

8. This portion of the deck slab shall be cast prior to the casting of the closure diaphragm.
9. This portion of the deck slab shall be cast monolithically with the closure diaphragm. Minimum width of deck slab to be cast with the diaphragm shall be 4'-0" (2'-0" on each side of pier centerline). For skew angles greater than 20°, adjust width of deck slab as necessary to ensure that this portion of the deck slab covers the entire closure diaphragm. This dimension shall be shown on the Deck Slab Concrete Placement Schedule.

10. For plan view of closure diaphragm, see File No. 12.15-9.

11. For details of bearing assemblies, see standard BBD-8 in Part 3 of this manual.

For location of section cuts and notes, see File No. 12.15-6 and above.
For location of section cuts and notes, see File No. 12.15-6 and -7.
PLAN VIEW OF CLOSURE DIAPHRAGM

0° SKEW

Details shown for AASHTO Types II, III and IV (not Types V or VI)
POST-TENSIONED CONCRETE:

Post-tensioned Structures:

Structures requiring post-tensioning (using ducts and grouting) shall not be used without a design waiver approved by the State Structure and Bridge Engineer. Exempt are prestressed concrete voided slabs and prestressed concrete box beams with transverse ties (Part 5 of this manual). Post-tensioning is prohibited for substructures.

In addition to an approved design waiver, post-tensioned structures shall be in accordance with the following IIMs and the special provisions included in these IIMs:

IIM-S&B-91 General Requirements for the Usage, Design and Specification of Post-Tensioned Bridge Superstructures

IIM-S&B-92 General Requirements for the Usage, Design and Specification of Substructures Supporting Post-Tensioned Bridge Superstructures

IIM-S&B-93 Minimum Inspectability Requirements for Post-Tensioned Bridges

IIM-S&B-94 Requirements for Qualification, Job Site Testing and Acceptance of Grouts Being Used in Post-Tensioned Structures