

Chapter 9 — Deck Design

9.1—GENERAL DECK CRITERIA

Concrete decks supported on longitudinal girders – except as listed in §9.2.4 – may be designed using the empirical deck design in accordance with the current AASHTO LRFD Bridge Design Specifications and the guidance in this Chapter.

Information on deck protection systems is given in §7.2.

All deck elevations on the plans shall be given at top of cast in place concrete deck unless otherwise noted.

Coordinate with other disciplines for elevations of additional surfacing.

9.2—CAST-IN-PLACE DECKS

9.2.1—Deck Thickness for New Construction and Redecks

Deck thickness, including 1/2 in. sacrificial wearing surface, shall be as shown Table 9.1. For NU Girders Table 9.2 has been compiled for ease of use

Integral sacrificial wearing surface is considered in design of all decks regardless of initial construction methodology. It is assumed that if a AC+M overlay is replaced in the future the deck will have to be ground in order to provide a good bonding surface for the replacement membrane.

A diagram of the interpretation of LRFDBDS Article 9.7.2.3 effective length and design depth is shown in Figure 9.1.

Bridge Division no longer permits 7 1/2 in. thick decks on new and reconstruction projects.

The ratio of effective length to design depth was set at approximately 16 when creating Table 9.1 and Table 9.2. This ratio exceeds the original maximum ratio of 15 in the *Ontario Highway Bridge Design Code* (1991) where the empirical method originates but is less than subsequent research conducted by Hays et al. (1988). Bridge Division feels this is a good balance between cost effectiveness and limiting girder-to-deck stiffness ratio to reduce cracking.

Table 9.1—Deck Thickness based on Effective Length

Deck Thickness	Maximum Effective Length
8 in.	10 ft. 0 in.
8 1/2 in.	10 ft. 8 in.
9 in.	11 ft. 4 in.
9 1/2 in.	12 ft. 0 in.
10 in.	12 ft. 9 in.
10 1/2 in.	13 ft. 4 in.
11 in.	13 ft. 6 in.

Table 9.2—Deck Thickness for NU Girders

Deck Thickness	Maximum Center-to-Center Spacing
8 in.	12 ft. 3 in.
8 1/2 in.	12 ft. 11 in.
9 in.	13 ft. 7 in.
9 1/2 in.	14 ft. 3 in.
10 in.	15 ft. 0 in.

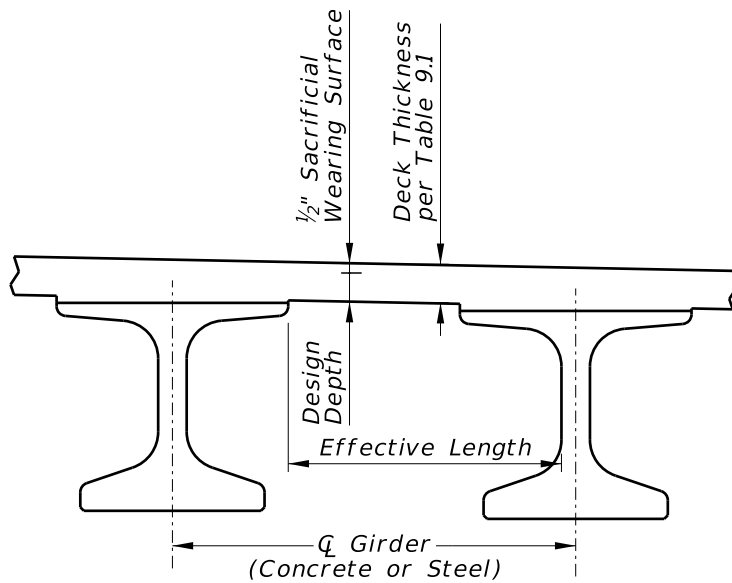


Figure 9.1—Effective Length and Design Depth

9.2.2—Reinforcement Details

All reinforcement in the deck and rails shall be epoxy coated.

Table 9.3—Deck Reinforcement

Deck Thickness	Main Reinforcement Spacing	Overhang Reinforcement between Each Full Width Bar
8 in.	12 in.	2
8 1/2 in.	12 in.	2
9 in.	11 in.	2
9 1/2 in.	11 in.	2
10 in.	10 in.	1
10 1/2 in.	10 in.	1
11 in.	9 in.	1

9.2.2.1—Transverse Bars

The clear cover for transverse bars shall be as stated in §5.3. The transverse bar spacing shall be measured along the centerline roadway and placed perpendicular to girders with bar sets provided at the end of floor where necessary for skewed structures. All reinforcement shall be #5 bars at the maximum spacing as shown in Table 9.3. Layers of reinforcement shall be staggered so the two mats do not have bars directly above one another.

Bridge Division has chosen to make reinforcement requirements for the top and bottom mats the same due to ease of detailing and construction.

9.2.2.2—Longitudinal Bars

Longitudinal bar layouts shall begin 3 in. from the edge of deck. All reinforcement shall be #5 bars at the maximum spacing as shown in Table 9.3. Layers of reinforcement shall be staggered so the two mats do not have bars directly above one another.

Additional reinforcement shall be provided in deck on structures continuous over the intermediate supports.

Bar sizes above #6 are not permitted in the deck reinforcement until longitudinal empirical deck steel has been upsized above the intermediate supports to #6 and both layers of additional negative moment steel contain (2) #6 bars between each empirical deck rebar. Maximum bar size used in a typical reinforced concrete deck shall be #9 unless approved by Bridge Division. Minimum clear space between bars shall be 2 ³/₄ in.

Lap splices are at the option of the contractor for bars up to 60 ft. For bars over 60 ft. the lap lengths shall be given in the plans and included in the plan quantity. Lap splices shall be staggered so that no two adjacent bars are spliced in the same place unless specified in the bridge plans. A detail similar to the lap detail provided on the bridge rail base sheets shall be provided on the Plans.

9.2.2.3—Skewed Decks

Additional end zone reinforcement will not be required in the deck at the turndown or integral abutments. In other situations where the skew requirements of LRFDBDS Article 9.7.2.5 applies, additional reinforcement in the deck end zones is required.

9.2.3—Cantilever Design

The design section for negative moments and shear forces on steel I-beams and precast I-shaped concrete beams shall be taken as one-quarter the flange width from the centerline of support.

Minimum overhang thickness shall match the uniform thickness of the remainder of the deck.

For empirical method decks with design overhangs of up to 4 ft. 6 in., supplemental #6 bars shall be provided in the overhang. Two bar marks shall be created as shown in Figure 9.2. Where two supplemental bars are required between each full width bar, one of each bar mark shall be in each space. Where only a single supplemental overhang bar is required between each full width bar, the bar marks shall be alternated between each full width bar.

For design overhangs greater than 4 ft. 6 in. or traditionally designed decks, calculations shall be completed by the designer per Appendix A13.4 of the LRFDBDS.

See additional information in §5.5.1.5.2.

Negative reinforcement steel should be added to the bottom mat prior to using #9 bars in a single layer of the deck reinforcement.

Upsize the longitudinal empirical deck bars to add additional moment capacity where required instead of using a full-length #5 bar in conjunction with two large supplemental bars. More medium size bars is better for crack control than one small bar and two large bars.

The LRFDBDS requirement for adding additional steel is not being followed due to the interaction with concrete turndowns at the abutment. The theory is that because of the stiffness at the turndown that additional reinforcement is not needed (Okumus et al., 2018).

Due to the thin nature of NU girder flanges as well as the bond breaker applied to the edge of the flanges Bridge Division has chosen to use b/4 for the cantilever point on decks for both steel and concrete girders in lieu of what is shown in LRFDBDS Article 4.6.2.1.6 for concrete girders.

Minimum overhang length should typically follow LRFDBDS Empirical Deck design.

Designers should note that loads given in Table A13.2-1 of LRFDBDS 9th Edition are out of date. If running cantilever calculations updated loadings can be found in (Transportation Research Board et al., 2024).

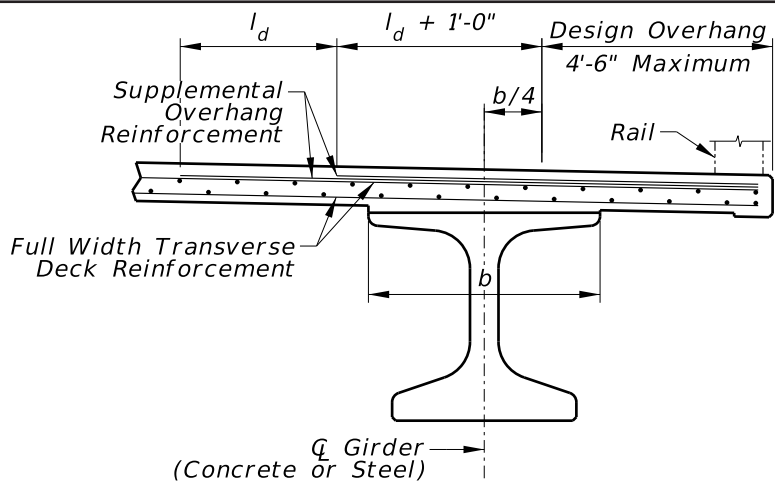


Figure 9.2—Cantilever Length and Reinforcement Section

9.2.4—IT Girder Decks

The maximum overhang length measured from the centerline of the exterior girder to the edge of the deck shall be 19 in.

9.2.4.1—Interstate and Heavy Barriers

When Inverted Tee girders are used on structures that carry interstate traffic or where barriers 39 in. or taller are used, cast-in-place deck thickness shall be 8 in. measured at the location of rod reading as shown in “Figure 9.12—SHIM SHOT IT Cell (Bridge Deck Library)”.

Top and bottom reinforcement shall be #5 bars both directions. Bottom mat spacing shall be 12 in. centers each direction and top mat spacing shall at 9 in. centers each direction. Cantilever reinforcing shall be per §9.2.3 with a single bar between each #5 and the 8 in. deck thickness shall be maintained. Additional reinforcement shall be provided in the deck on structures continuous over the intermediate supports.

9.2.4.2—Other Structures

Cast-in-place deck thickness is 6 in. measured at the location of rod reading as shown in “Figure 9.12—SHIM SHOT IT Cell (Bridge Deck Library)”.

Deck reinforcement is a single layer of reinforcement at mid deck thickness. All reinforcement shall be #5 bars. Transverse spacing shall be 6 in. centers and longitudinal spacing shall at 10 in. centers. No additional reinforcing is required in the cantilever and the 6 in. deck thickness shall be maintained. Additional reinforcement may be required in the deck on structures continuous over intermediate supports.

9.2.5—Construction Joints and Pour Sequencing

A pouring diagram and note shall be placed on the General Plan and Elevation Sheet of the Plans. The note is available as the cell shown in “Figure 9.13—POURSQ Cell (Bridge Deck Library)”. The values in the cell text must be filled in after placing it on the sheet. When a continuous placement sequence is permitted standard note #048 shall be placed with the cell, when skip placement is mandatory standard note #049 shall be placed with the cell.

Alternate procedures for placing deck concrete may be submitted for approval by the Contractor along with a statement of the proposed method and evidence that the contractor possess the necessary equipment and facilities to accomplish the required results. The Project Manager, PCC Pavements Research and Development Engineer, and Bridge Division will determine if their plan is acceptable.

Any alternate pouring sequence must be determined before submittal of fabrication plans for steel girders and prior to casting of any bearing pedestals on substructures. The camber and blocking diagram in the plans for steel bridges is representative of the pouring diagram shown in the bridge plans.

All design checks, including uplift at supports, must be verified before the Engineer approves a revised pour sequence.

For detailing information on the construction joints see §5.4.2.

9.2.5.1—Continuous Placement Sequence

Continuous placement is the default choice for structures where it is feasible from a construction and design standpoint. It is easier for the Contractor and more likely to result in a deck with no transverse construction joints.

Optional transverse construction joints shall be detailed for placement of concrete slabs and bridge decks. The location of these transverse joints will be near the dead load moment point of contraflexure (Strength I load combination).

On continuous spans a pour shall only be terminated at the completion of a positive moment area.

9.2.5.2—Skip Placement Sequence

Skip placement sequence consists of mandatory transverse construction joints that are placed near the dead load moment point of contraflexure (Strength I load combination). All positive moment sections are placed prior to any negative moment section being placed.

Continuous for dead load steel superstructures with one or more spans exceeding 150 ft. in length, shall be detailed with skip placement sequence as mandatory.

Bridges with many spans may require an alternate pouring sequence regardless of maximum span length. Contractors are allowed to submit alternate pouring sequences regardless of maximum span length.

Structures that are unable to be poured in a continuous path along the length will be detailed with the skip placement sequence based on pour diagram calculations in §9.2.5.3.

9.2.5.3—Pouring Diagram Calculations

The minimum pour rate shall be calculated based on the following assumptions:

- The rollers and carriage travel at 80 ft./min. transverse to the finishing machine (along support skew).
- The rollers can finish in both directions of travel for non-skewed structures. For skewed structures the rollers can only finish in one direction of travel. The carriage is then returned to the first side of the pour without a finishing pass.
- The finishing machine travels 9 in. per finishing pass along the centerline of the roadway regardless of skew.
- Normal concrete remains plastic for three hours.
- Maximum concrete delivery rate is 80 yd³/hr.

Based on these assumptions a minimum pour rate in ft./hr. along the centerline of bridge can be determined that will keep the concrete plastic between construction joints.

Initial set time is a conservative assumption from the 47BD data collected in Morcoux et al. (2023).

Take the hypothetical bridge shown in Figure 9.3. The structure has a 28 ft. clear width, 10° skew, and 24.85 ft.² average cross section area for deck (including the girder haunches).

- the finishing machine requires a pass each direction across the bridge even though it only finishes in one direction due to the skew.

$$\frac{\frac{28 \text{ ft.}}{\cos 10^\circ} \times 2}{80 \frac{\text{ft.}}{\text{min.}}} = 0.71 \frac{\text{min.}}{\text{pass}}$$

- maximum finishing rate

$$\frac{9 \frac{\text{in.}}{\text{pass}} \times \frac{1 \text{ ft.}}{12 \text{ in.}}}{0.71 \frac{\text{min.}}{\text{pass}} \times \frac{1 \text{ hr.}}{60 \text{ min.}}} = 63.3 \frac{\text{ft.}}{\text{hr.}}$$

- maximum concrete delivery rate

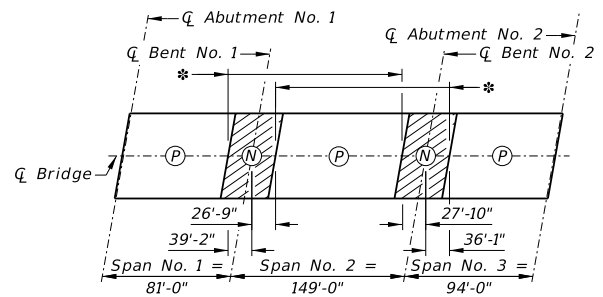
$$\frac{80 \frac{\text{yd.}^3}{\text{hr.}} \times \left(\frac{3 \text{ ft.}}{1 \text{ yd.}}\right)^3}{24.85 \text{ ft.}^2} = 86.9 \frac{\text{ft.}}{\text{hr.}}$$

- minimum pour rate to ensure plastic concrete along entire pour. The longest positive plus negative section, regardless of chosen pour direction needs to remain plastic during the pour.

$$\frac{39.17 \text{ ft.} + 149 \text{ ft.} - 27.82 \text{ ft.}}{3 \text{ hr.}} = 53.4 \frac{\text{ft.}}{\text{hr.}}$$

Therefore the plans shall show a minimum pour rate of 53.4 ft./hr. along with the pouring diagram as shown in Figure 9.3.

Should the pour rate to ensure plastic concrete exceed the maximum finishing or delivery rates, skip pouring shall be denoted as mandatory in the pouring diagram.



* Optional Construction Joints (Pour in direction of arrows) Contractor shall maintain a minimum placement and finishing rate of at least 53.4 feet/hour along \bar{C} Bridge. Should the Contractor not possess the necessary equipment and facilities to maintain the minimum placement and finishing rate, the slab shall be placed in sections. All Positive moment sections of the slab shall be placed followed by placement of the Negative moment sections of the slab. Alternate procedures for placing deck concrete may be submitted for approval by the Contractor.

Figure 9.3—Example Pouring Diagram

Alternatives if the contractor cannot maintain this pour rate or concrete cannot be placed and finished fast enough to maintain plasticity between construction joints, listed in order of preference

- A. Skip pouring, see §9.2.5.2
- B. Admixtures to increase the length of time concrete remains plastic. This option is less preferred due to the inherent lack of certainty with admixture performance.
- C. Add a longitudinal deck construction joint

Minimum pour rates determined using this methodology are likely to be significantly higher than the 20 ft./hr. for bridge decks specified in paragraph 3.d. of subsection 706.03 in the Standard Specifications. The pour rate required must be given on the plans for it to govern over the minimum pour rate given in the Standard Specifications.

9.2.6—Drip Bead Detail

A drip bead shall be placed on all bridge decks and concrete slab bridges. The cell shown in "Figure 9.14—DRIPBnew Cell (Bridge Deck Library)" shall be used for open rail bridges. The cell shown in "Figure 9.15—DRIPB Cell (Bridge Deck Library)" shall be used for closed rail bridges, approaches, and bridge decks with a single layer of reinforcement.

9.2.7—Roadway Crown

Crown of the bridge deck shall be shown on all Plans. The cell shown in "Figure 9.16—CROWN Cell (Bridge Deck Library)", is available for a standard 2% crown.

Bottom of the deck shall be set as a straight line between girder shims.

9.2.8—Phased Decks

Bridge decks to be built under phasing shall meet the empirical deck cantilever requirements for the overhang that is open to traffic or as loading requires. Consideration should be provided for phased traffic and temporary barriers for existing and new decks in cantilever condition.

Designs shall include closure pours whenever the differential dead load deflection exceeds 2 in. Preliminary analysis of girder deflections may be necessary to determine if phased construction is feasible. Girder deflections at each phase shall be considered when adjusting the shim to the deck. When closure pours are required, standard note #010 shall be shown and the details showing the left out separators shall be shown in the typical cross section.

Typical closure pour width shall be 4 ft when using standard clear cover specified in §5.3.

Bottom clear cover on transverse reinforcement may be adjusted to reduce splice length at construction joints, but core depth must follow LRFDBDS requirements for Empirical Deck Design.

For example, take the girder phasing shown in Figure 9.4. Deflections to account for on Girder C

- Non-composite deflections
 - Self weight of the girder
 - Prestressing (if applicable) and losses per §5.2.1.5.
 - Camber cut/formed into steel girders
 - Phase I deck pour (consider actual pour width)
- Partial width composite deflections (consider actual Phase I pour width in determining moment of inertia at this phase)
 - Temporary safety barrier
 - Wearing surface applied to Phase I prior to Phase II construction (if applicable, some wearing surfaces are applied full width after the bridge deck is fully poured)
 - A portion of Phase I permanent rail

Deflections to account for on Girder D

- Self weight of the girder
- Prestressing (if applicable) and losses per §5.2.1.5.
- Camber cut/formed into steel girders

The difference between these two deflection values is the differential deflection between Girder C and Girder D.

Greater than 2 in. deflection listed in the deflections for shims table on the girder data sheet does not necessarily mean a structure requires a closure pour.

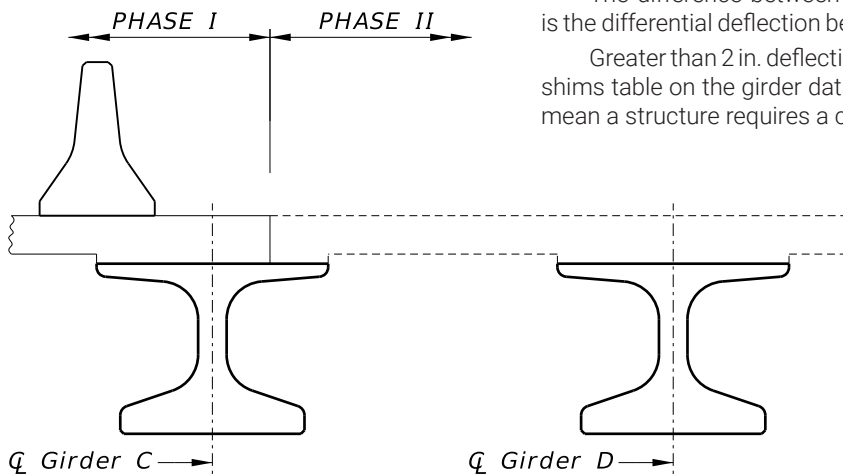


Figure 9.4—Differential Deflection Cross Section (for illustrative purposes)

9.2.9—Stay in Place Forms

Metal stay in place forms are allowed if identified as allowed on the BDS. The forms shall support the weight of the plastic concrete deck and any corresponding construction loads. Shop drawings shall be submitted to NDOT as information only. After construction these forms provide no structural function. All corresponding bridge elements shall be designed for stay-in-place forms load based on §3.3. Refer to *Standard Specifications* (§704.03.6.g) for more information.

9.2.10—Widening

Match new reinforcement to the greater of :

- Existing deck reinforcement
- Reinforcement for a newly constructed bridge deck per §9.2.2.

Overhang reinforcement shall be per §9.2.3.

9.3—NU DECK

Reserved for future use.

For more information see Morcous et al. (2013).

9.4—COMPOSITE ACTION ON CONCRETE GIRDERS

Where a haunch tall enough to prevent the SWWR projecting from the girder from developing within the CIP deck properly (per §9.4.2) is detected (either in design phase or during shim shots) supplemental reinforcement shall be provided.

Supplemental reinforcing “hat bars” may be necessary following shim survey measurements to satisfy requirements. Supplemental hat bar plan and quantity along with additional shim concrete quantities shall be provided after the results of the girder survey.

It is recommended to issue some estimated amount of supplemental reinforcement with the letting set so that construction can continue without waiting for procurement of the supplemental reinforcement.

Supplemental reinforcement spacing need not match spacing of SWWR wires.

9.4.1—Design Assumptions

Shear friction calculations (per LRFDBDS Article 5.7.4) shall be run for:

- The interface between the precast girder and the bottom of cast-in-place haunch
- The interface between the top of the cast-in-place haunch and the bottom of the cast-in-place deck
- Other interfaces as required, such as for threaded rod connected I-Girders discussed in §5.5.3.

Reduced interface width shall be accounted for in interfaces where full bond stress may not be achieved.

NDOT base sheets show 8 in. each side of NU Girder top flanges to be smooth with bond breaker.

9.4.2—Reinforcement Development

To be considered effective for horizontal shear transfer reinforcement must be embedded within the core of the slab, above the bottom mat of longitudinal reinforcement in the deck.

Preferred supplemental reinforcement where provided SWWR in girders is not tall enough to engage the CIP can be seen in Figure 9.5.

The 5 in. standard extension of precast stirrups provides enough development length near the location of minimum haunch to satisfy anchorage requirements. Where thicker haunches are anticipated designers may investigate the feasibility of using larger projections to avoid hat bars.

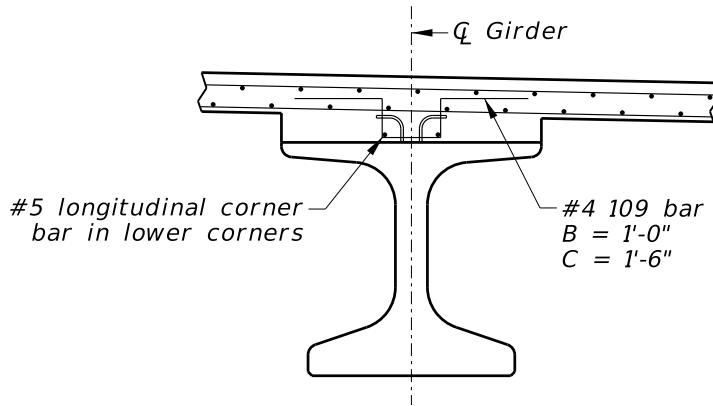


Figure 9.5—Preferred Hat Bar Detail

9.5—TURNDOWNS AND DIAPHRAGMS

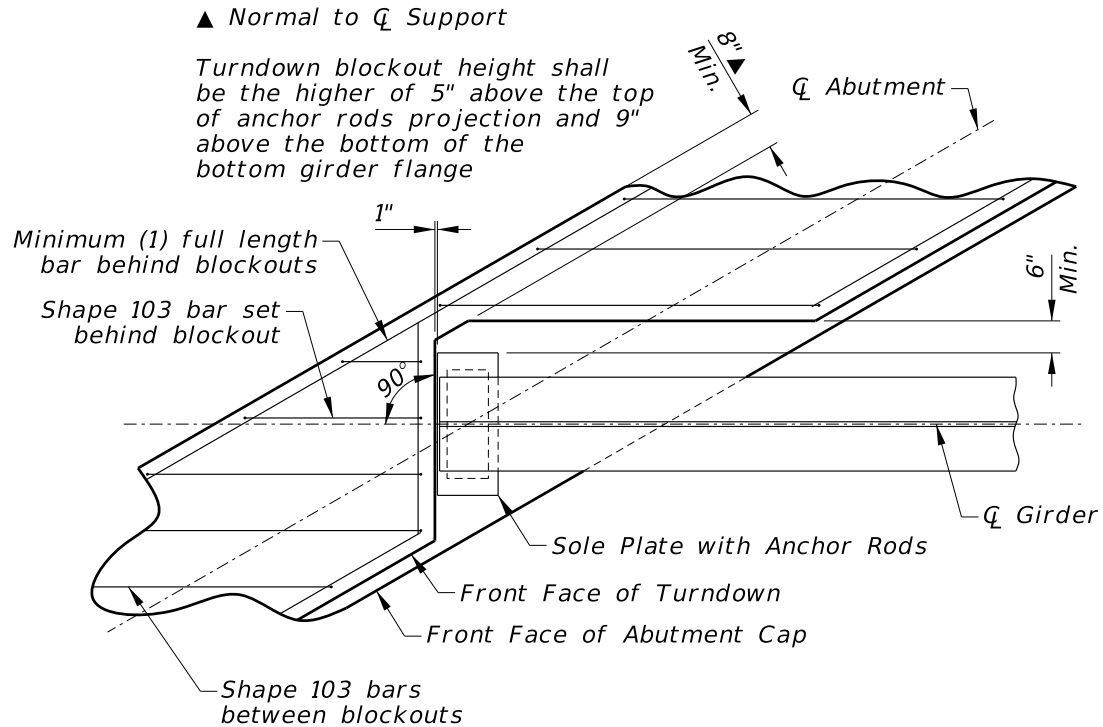
A #6 reinforcing bar shall be placed in the hooks of the extended prestressing strand to improve the effectiveness of the anchorage of the reinforcement. The length of reinforcing placed in the hook shall be the width of the girder bottom flange, except at locations where splayed strands are used. Full length bars are not permitted on bridges with skew as they will not be able to simultaneously anchor strands and run parallel to the skewed substructure.

Bars in the corner of extended strands do not need to be developed to be used for anchorage.

9.5.1—Blockouts for Anchor Rods

Mandatory block outs shall be shown on the plans in concrete turndowns/diaphragms that utilize anchor rods see [Figure 9.6](#) for recommended layout.

See §14.2.10 for discussion of when anchor rods may be required at bearings.



Schematic details for turndowns at abutments and intermediate support diaphragms can be seen in [Figure 9.7](#) through [Figure 9.11](#) and can be used as detail guidelines.

Details shown are the minimum reinforcement and designers should calculate the required reinforcement on a case-by-case basis.

9.5.2—Slab Turndown at Abutments

The front face of a slab turndown shall be setback 2 in. minimum from the front face of the abutment cap. The back face of a slab turndown shall be flush with the back face of the abutment cap for abutment caps not greater than four feet wide. Slab turndowns shall be detailed with a 4 in. chamfer from bottom of bridge deck to front face of turndown.

The minimum approach slab seat length shall be 1 ft. 0 in. long measured along the centerline of the Roadway. A mandatory construction joint shall be detailed at an elevation between the approach slab seat and bottom of the bridge deck.

Extended strands on shallow girders at abutments should be detailed to miss approach slab seat blockouts. Use 180° hooks in lieu of 90° if necessary.

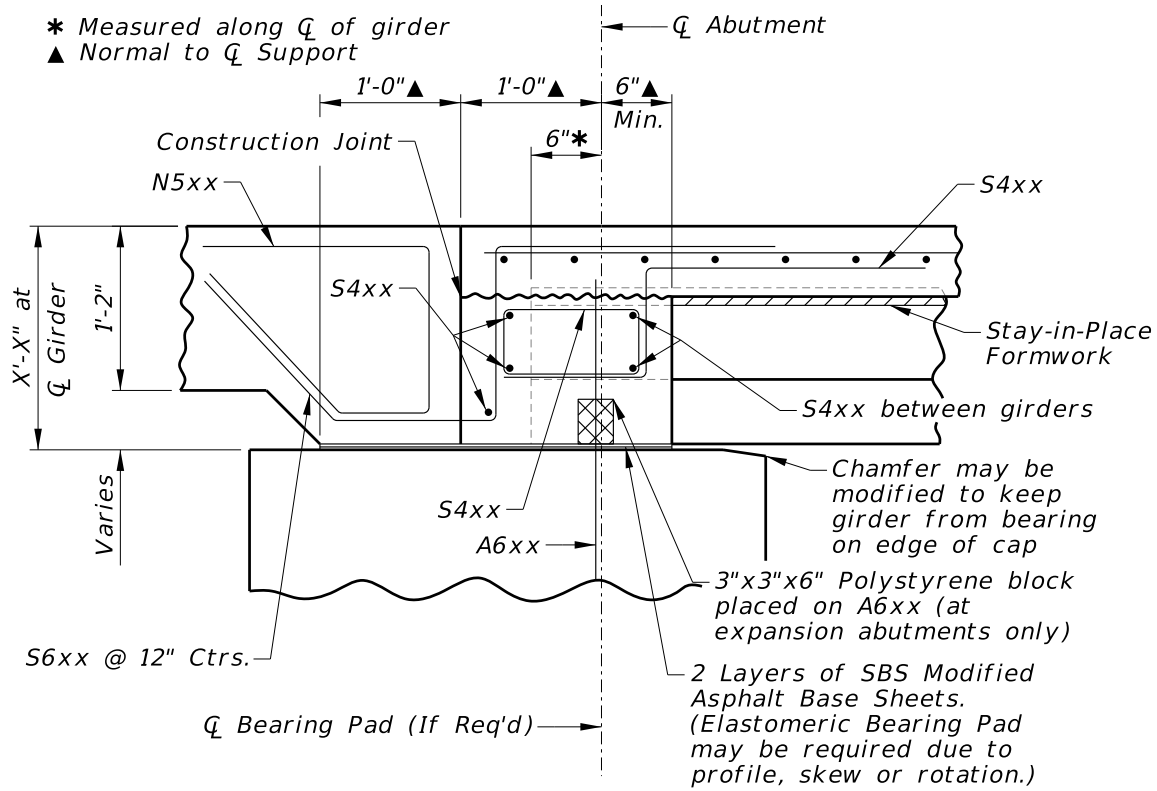


Figure 9.7—IT Girder Slab Turndown (Required on IT 300, Optional on IT 400)

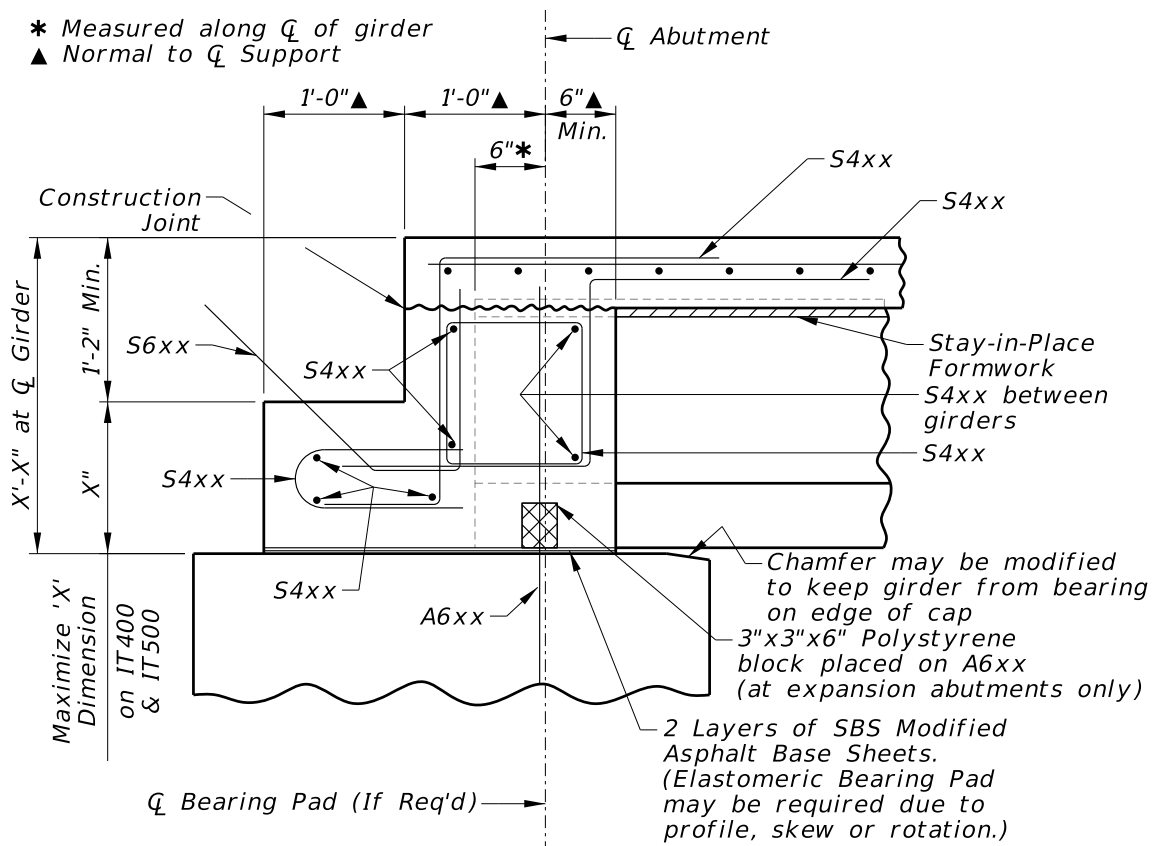


Figure 9.8—IT Girder Slab Turndown (Required on IT 500 and Deeper, Optional on IT 400)

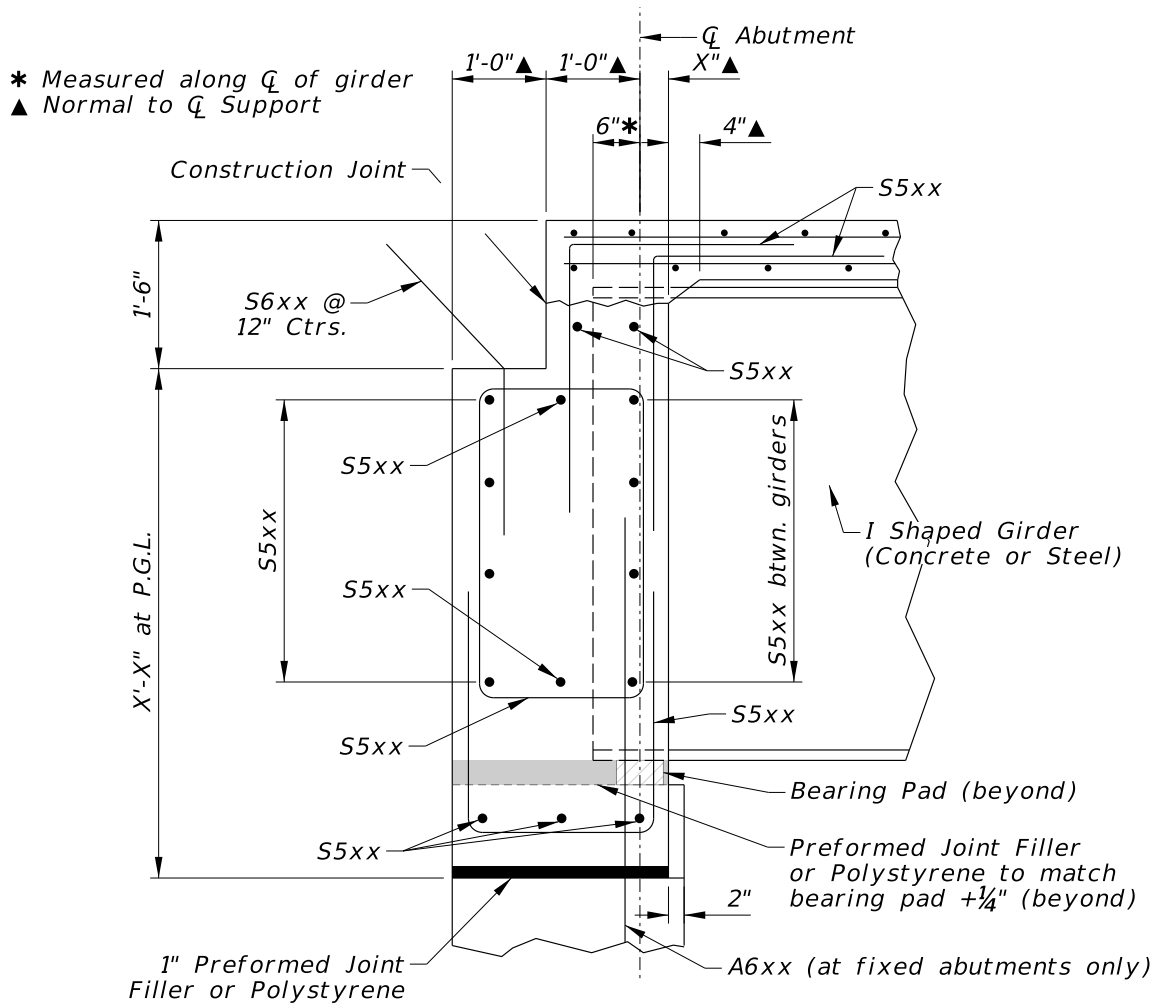


Figure 9.9—I Shaped Girder Slab Turndown (Concrete or Steel)

9.5.3—Diaphragm at Intermediate Supports

Ahead station and back station faces of diaphragms shall be set back 2 in. from the respective face of the substructure cap. Diaphragms shall be detailed with 4" chamfer from bottom of bridge deck to ahead station and back station faces of diaphragm.

A mandatory construction joint shall be detailed at a location approximately $\frac{1}{3}$ of the girder depth below the bottom of the bridge deck.

A flush concrete Diaphragm, where the end of the diaphragm matches the exterior girder profile, shall be used at all overpass structures where the lower roadway is of State Functional Classification Major Arterial or higher. When a flush concrete diaphragm is used the cell shown in "Figure 9.17—Ext. Strand Splay Cell (NU Details Library)" is provided for use on the plans. For all other locations, the concrete Diaphragm shall be extended beyond the exterior girder.

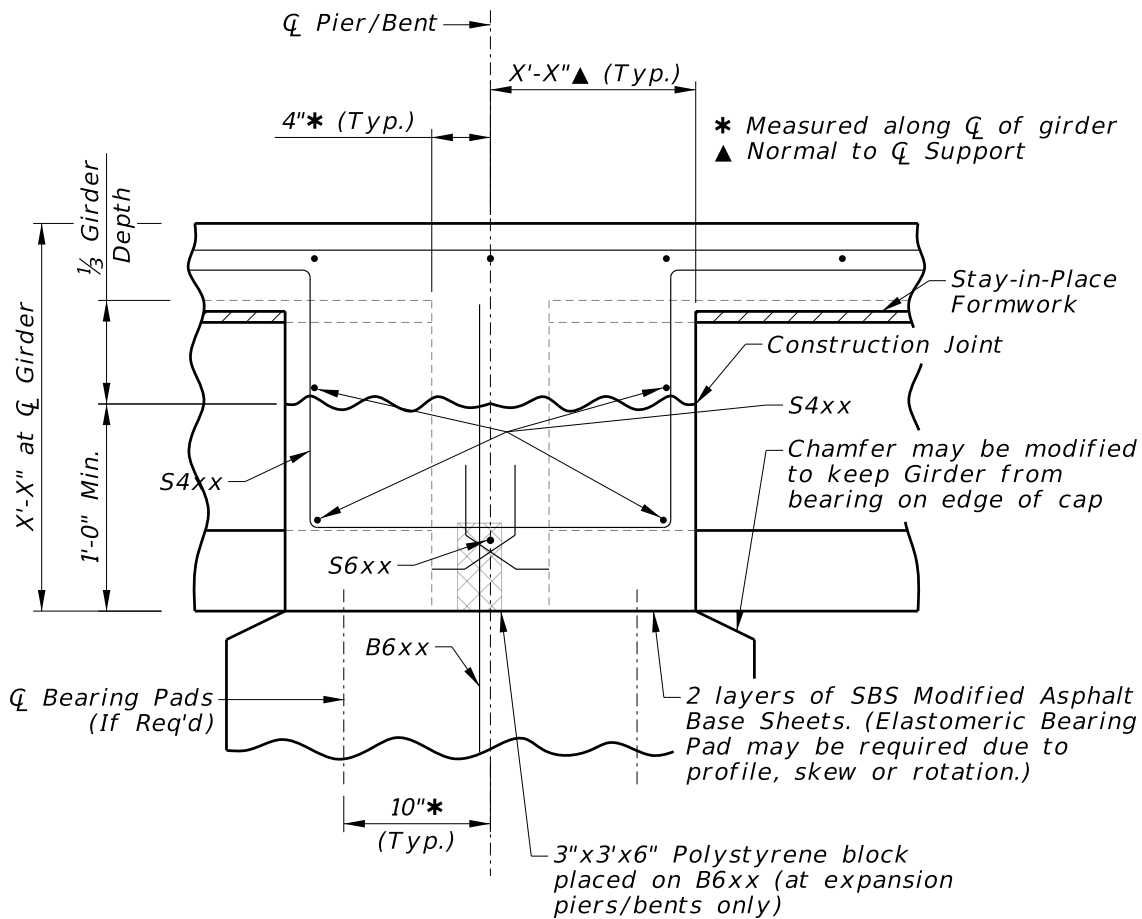


Figure 9.10—IT Girder Diaphragm

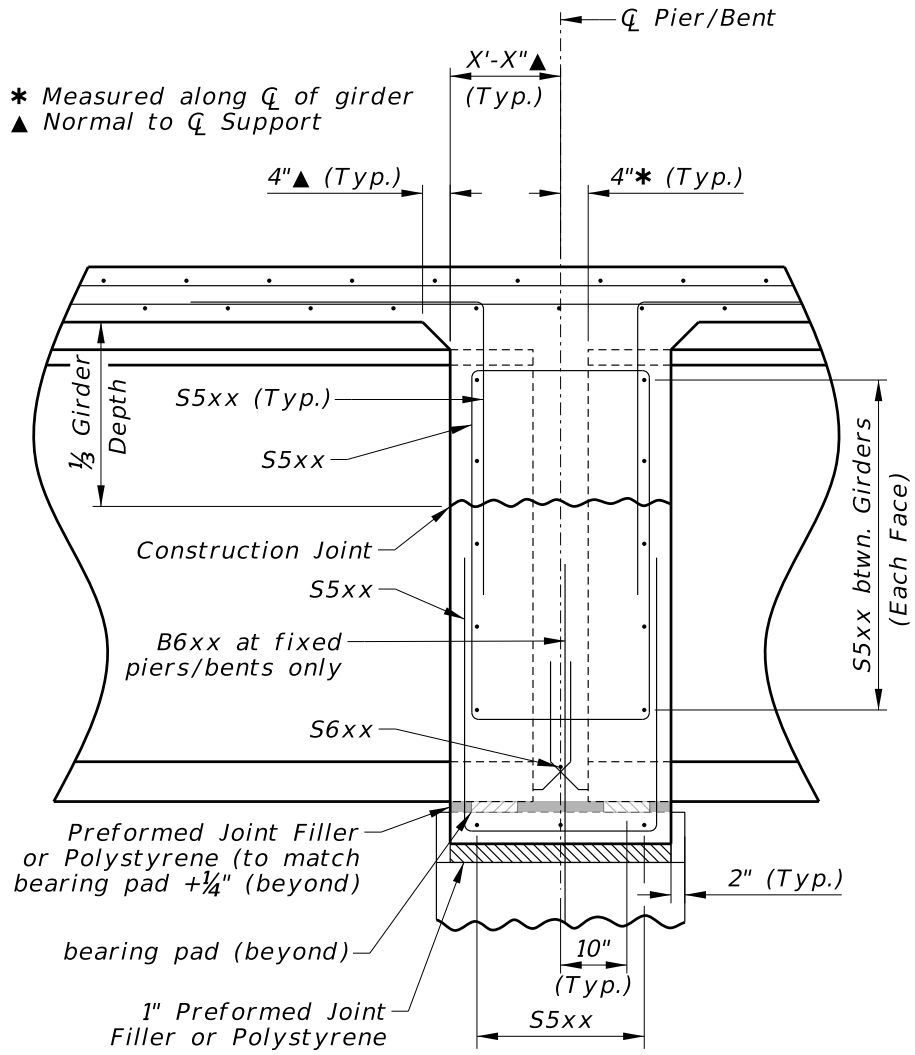


Figure 9.11—I Shaped Girder Diaphragm (Concrete or Steel)

9.6—REFERENCES

Hays, C. O., Lybas, J. M., & Guevara, J. O. (1988). *Tests of the Punching Shear Strength of Lightly Reinforced Orthotropic Bridge Decks* (No. FL/DOT/MO/340/88). Florida Department of Transportation & University of Florida. <https://www.fdot.gov/structures/structuresresearchcenter/completedresearch.shtm>

Highway Engineering Division. (1991). *Ontario Highway Bridge Design Code* (3rd Edition). Highway Engineering Division, Ministry of Transportation and Communications.

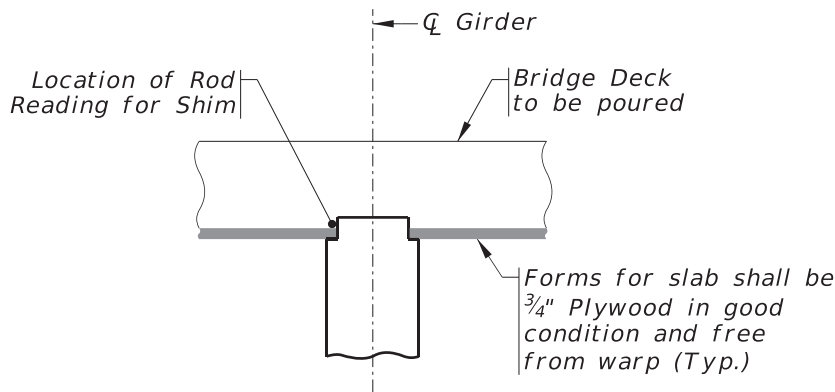
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Okumus, P., Oliva, M. G., & Arancibia, M. D. (2018). *Design and Performance of Highly Skewed Deck Girder Bridges* (Technical Report N° 0092-16-05). University at Buffalo, the State University of New York University of Wisconsin, Madison. <https://wisconsindot.gov/documents2/research/0092-16-05-final-report.pdf>

Transportation Research Board, Holt, J. M., Lopez, M. D., Murphy, T. P., Steelman, J. S., Rosenbaugh, S. K., Loken, A. E., Faller, R. K., Galvan, M., Bloschock, M., & National Cooperative Highway Research Program. (2024). *NCHRP Research Report 1109: Bridge Railing Design Requirements*. National Academies Press. <https://doi.org/10.17226/27893>

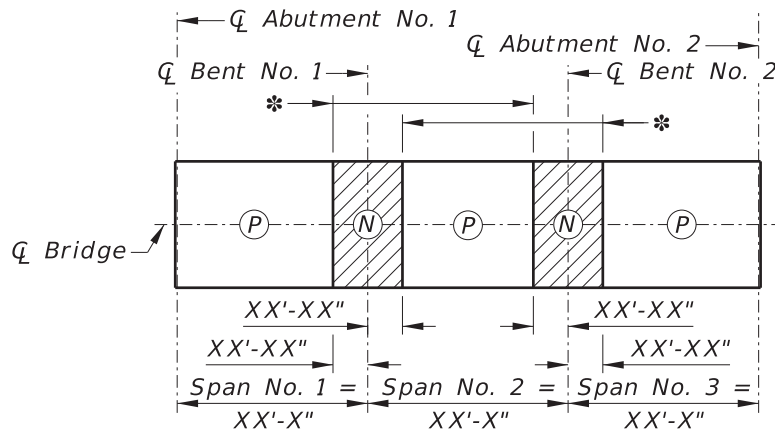
9.7—REFERENCED CELLS



SHIM SHOT LOCATION

NOTE:
 Rod person shall stand on an adjacent IT girder while taking shim shots.

Figure 9.12—SHIM SHOT IT Cell (Bridge Deck Library)



POURING SEQUENCE:

The entire slab shall be poured starting at either end and proceeding to the other end, stopping at the completion of any "P" section.

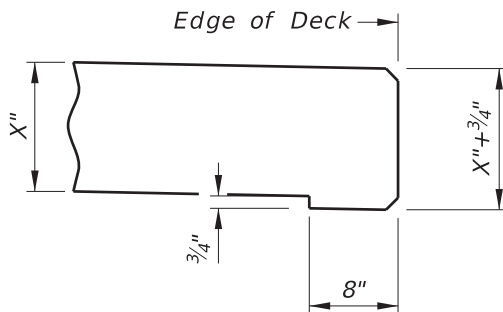
- Ⓟ = Positive moment section
- Ⓝ = Negative moment section

* Optional Construction Joints (Pour in direction of arrows)

POURING DIAGRAM

Not to Scale

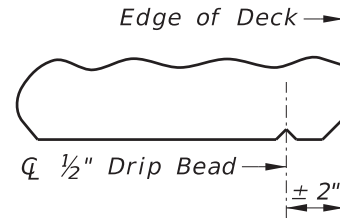
Figure 9.13—POURSQ Cell (Bridge Deck Library)



DRIP BEAD DETAIL

Not to Scale

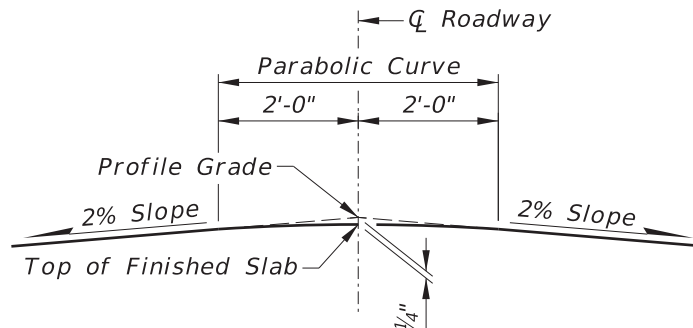
Figure 9.14—DRIPBnew Cell (Bridge Deck Library)



DRIP BEAD DETAIL

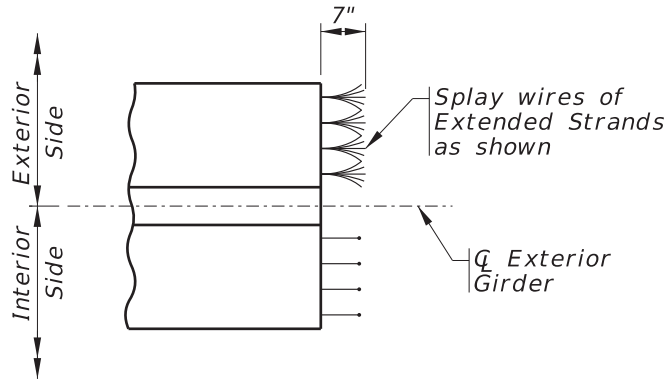
Not to Scale

Figure 9.15—DRIPB Cell (Bridge Deck Library)



CROWN TEMPLET

Figure 9.16—CROWN Cell (Bridge Deck Library)



EXTERIOR STRAND SPLAY DETAIL

Showing Bottom Flange in Plan View

Figure 9.17—Ext. Strand Splay Cell (NU Details Library)