INDIANA DEPARTMENT OF TRANSPORTATION

Driving Indiana's Economic Growth

Design Memorandum No. 22-19

September 13, 2022

TO: **All Design, Operations, and District Personnel, and Consultants**

FROM: ***/s/ Stephanie J. Wagner***
Stephanie J. Wagner
Director of Bridge Engineering

SUBJECT: **Welded Wire Reinforcement (WWR), Lightweight Concrete, and Continuity for Prestressed Beams**

REVISES: ***Indiana Design Manual* (IDM) Chapter 406-4.02, 406-4.03, 406-4.04, 406-5.01, 406-10.0, 406-12.02(01), 406-12.02(02), 406-12.02(03), 406-12.03(01), 406-12.03(03), 406-12.04(02), 406-12.05, 406-12.06, 406-12.08, 406-12.09**

Figures 406-12B (del.), 406-12C (new), Figures 406-13A thru 406-13D (revised), and 406-14A thru Z (deleted, content revised and consolidated into new figures 406-14AA thru EE)

EFFECTIVE: **Stage 3 submittals on or after January 1st, 2023**

IDM Chapter 406, Prestressed-Concrete Structure, has been revised to incorporate welded wire reinforcing, WWR, as shear reinforcing, lightweight concrete considerations, design and detailing requirements for establishing continuity over piers, and guidance on how positive restraining moments should be considered in the design.

WWR provides some benefits over conventional mild reinforcing when used as shear reinforcing in prestressed concrete beams. *AASHTO LRFD Bridge Design Specifications*, 8th Edition with interim revisions through May 2018 requires the ends of stirrups be anchored with standard hooks when conventional deformed reinforcement is used. WWR used as shear reinforcing is only required by *LRFD* to be anchored by two longitudinal wires, which greatly reduces the congestion and potential reinforcement conflicts at the bottom of the beam. Fabrication time may also be reduced by using WWR, which can result in reduced beam costs. A potential downside to using WWR is the reduction in possible strand locations due to conflicts with the longitudinal wires used to anchor the vertical reinforcement. The IDM figures referenced in the heading of this design memo have been updated to show both conventional and WWR reinforcement and the associated strand patterns. Designers should use WWR in the design and detailing of prestressed beams whenever feasible and may begin its use prior to the effective date.

The use of lightweight concrete for prestressed beams should be limited to applications where weight reductions may have significant benefits during construction. These applications could include construction sites where crane access is severely limited or bridges over railroad facilities where higher factors of safety may be required by the railroad owner during construction. The reduced concrete weight is obtained by the use of lightweight concrete in the mix. This lightweight aggregate is more expensive and weaker than typical aggregate, which results in higher beam costs and lower attainable compressive strengths. The use of lightweight concrete in prestressed beams will require written approval from the Director of Bridge Engineering.

Multi-span prestressed beams that are made continuous over the interior supports are required to use concrete diaphragms that encapsulate the beam ends. This not only provides a mechanism for load transfer between the precast components, but also provides a significant amount of concrete cover for the strands that terminate at or extend past the ends of the prestressed beams. The flexural restraint caused by the pier diaphragms should always be considered in the design of the prestressed beams. The required time between casting the beams and establishing continuity at the piers should be noted on the plans and considered when estimating the construction duration.

For questions related to this design memo, please contact the Bridge Engineering Division at Bridgedesignoffice@indot.in.gov.

IDM Revisions

406-4.02 Normal-Weight and Lightweight Concrete [Rev. Oct. 2012, Jun. 2021, Sep. 2022]

The minimum f_c' for prestressed or post-tensioned concrete components should be shown on the plans. Such a strength outside the range shown in Section 406-4.02(1.) is not permitted without written approval of the Director of Bridge Engineering. See *LRFD* 5.4.2.2 for the coefficient of thermal expansion.
The following will apply to concrete.

1. The design compressive strength of normal-weight and lightweight concrete at 28 days, f_c', should be in the range as follows:

   a. prestressed box beam: 5 to 7 ksi
   b. prestressed I-beam: 5 to 7 ksi
   c. prestressed bulb-tee beam: 6 to 8 ksi

   An exception to the range shown above will be allowed for a higher strength if the higher strength can be documented to be of significant benefit to the project, it can be effectively produced, and approval is obtained from the Director of Bridge Engineering.

2. At release of the prestressing strands, f_c' should not be less than 4 ksi and should be determined during the beam design. The specified concrete compressive strength at release should be rounded to the next higher 0.1 ksi.

See Section 406-4.03 for limitations on the use of lightweight concrete.

406-4.03 Lightweight Concrete [Rev. Oct. 2012, Sep. 2022]

A significant benefit of lightweight concrete beams is the potential for smaller cranes required for setting beams in locations where access is limited, or over railroads where a higher factor of safety during construction is required. Lightweight concrete, as defined as having a unit weight, excluding the weight of reinforcing, of less than 0.135 kcf to as low as 0.120 kcf, may be used with written approval from the Director of Bridge Engineering. The reduced weight is obtained by the use of lightweight aggregate, which is generally weaker and more expensive than typical aggregate. Therefore, it's more difficult to achieve higher compressive strengths when using lightweight concrete, and the 28-day f'c should be limited to 8 ksi. Lightweight concrete also requires longer time in the casting beds to reach the required release strength, which will also increase fabrication costs and may have a negative impact on the supply of beams. Reductions in capacity and increases in development lengths, in accordance with LRFD, should be considered when evaluating the use of lightweight concrete.

406-4.04 Prestressing Steel [Rev. Sep. 2022]

Prestressing strands should be of the low-relaxation type with a minimum tensile strength of 270 ksi. Unless there is a reason to do otherwise, only the following three-strand diameters should be used.

1. Nominal 3/8 in., $A_s = 0.085$ in^2, for use in a stay-in-place deck panel.

2. Nominal 1/2 in., $A_s = 0.167$ in^2, for use in an I, bulb-tee, or box beam, or post-tensioned member.

3. Nominal 0.6 in., $A_s = 0.217$ in^2, for use in a in a bulb-tee beam or post-tensioned member.

See *LRFD* Table 5.4.4.1-1 for values of yield strength, tensile strength, and modulus of elasticity of prestressing strands or bars. The strand area and initial pull per strand should be shown on the plans.

Prestressing threadbars are used for grouted construction. If the bars are used for permanent non-grouted construction, the bars should be epoxy coated.

406-5.0 LIMIT STATES

406-5.01 General [Rev. Sep.2022]

In addition to service, fatigue, strength, and extreme-event limit states, prestressed or post-tensioned components should be investigated for stresses and deformations for each critical stage during construction, stressing, handling, transportation, and erection. The support locations used for handling and transportation checks should be in accordance with the *Standard Specifications*.

406-10.0 DEVELOPMENT OF PRESTRESSING STRANDS AND DEBONDING [REV. JUN. 2021, SEP. 2022]

The transfer length of pretensioned components is shown in *LRFD* 5.9.4.3. The specific requirements for development length and variation of pretensioned stress in strands for bonded or debonded strands are provided in *LRFD* 5.9.4.3.2 and 5.9.4.3.3. Where debonded, or shielded, strands are used, the following apply.

1. In a bulb-tee beam, not more than 25% of the total number of strands and not more than 40% in each horizontal row should be debonded. The allowable percentage of debonded strands for an AASHTO I-beam or a box beam should be not more than 50% of the total number of strands and of the strands in each horizontal row. Strands placed in the top flange of the beam should not be included in the percentages shown above.

2. Exterior strands in each horizontal row should not be debonded.

3. Bonded and debonded strands should preferably alternate both vertically and horizontally.

4. Debonding termination points should be staggered at intervals of not less than 3 ft.

5. Not more than four strands, or 40% of the total debonded strands, whichever is greater, should be terminated at one point.

   See *LRFD* 5.9.4.3.3 for additional guidelines.

6. Two strands should be considered in the top of a box beam, 2 or 4 strands in the top flange of an I-beam, or up to 6 strands in a bulb-tee beam. This can significantly reduce the need for debonded strands in the bottom of the beam, and it facilitates the placement of the top mild reinforcement. Where strands are placed in the top flange, a note should be shown on the plans indicating that these strands are to be cut at the center of the beam after the bottom strands are released and the pocket is then to be filled with grout.

7. Top strands in a concrete box beam should be placed near the sides of the box.

Minimum concrete cover for prestressing strands and metal ducts, and the general protection requirements for prestressing tendons are described in *LRFD* 5.14.

406-12.02(01) General [Rev. Sep. 2022]

The standard prestressed-concrete-member sections used are as follows:

1. AASHTO I-beam type I, II, III, or IV;
2. Indiana bulb-tee beams; and
3. Indiana composite and non-composite box beams.

To ensure that the structural system has an adequate level of redundancy, a minimum of four beam lines should be used.

AASHTO I-beams, Indiana bulb-tee beams, and Indiana wide bulb-tee beams should include embedded steel plates at the bearing locations, as shown in Figure 406-12C. These steel plates allow for the welded attachment of the bearing load plates and also mitigate spalling that can occur at the ends of the beams during fabrication.

The top flanges of AASHTO I-beams, Indiana bulb-tee beams, and Indiana wide bulb-tee beams should only be notched when required to provide sufficient clearance to the pavement ledge and end bent diaphragm reinforcement. The webs of these beams should only be notched if they conflict with the pavement ledge. For all new bridges, or when feasible in bridge preservation projects, the end bents should be made sufficiently wide to eliminate the need for notching the tops of webs. The use of web notches is discouraged due to cracking that may occur at the interior corners of web notches of prestressed beams.

An alternative prestressed-concrete-beam section may be considered if its use can be justified. The use of a beam section not available through local producers will be more expensive if the forms must be purchased or rented for a small number of beams. One or more beam fabricators should be contacted early in project development to determine the most practical and cost-effective alternative beam section for a specific site.

406-12.02(02) AASHTO I-Beam Type I, II, III, or IV [Rev. Sep. 2022]

See Figures 406-13A through 406-13D for details and section properties. I-beam type IV should not be used unless widening of an existing bridge is required. The 54-in.-depth beam should be used for a new structure where this member depth and span length is required. Draped strands may be considered for use in AASHTO I-beams if tensile stresses in the top of the beam near its end are exceeded if using straight strands, or to increase shear capacity near beam ends.

406-12.02(03) Indiana Bulb-Tee Beam [Rev. Oct. 2012, Sep. 2022]

See Figures 406-14AA through 406-14EE for details and section properties. For a long-span bridge, bulb-tee beams with a top-flange width of 60 in. should be considered for improved stability during handling and transporting. Draped strands may be considered for use in a bulb-tee beam if tensile stresses in the top of the beam near its end are exceeded if using straight strands, or to increase shear capacity near beam ends. The maximum allowable compressive strength, tensile strength, extent of strand debonding, and number of top strands should be considered in evaluating the need for draped strands. If draped strands are used, the maximum allowable hold-down force per strand should be 3.8 kip, with a maximum total hold-down force of 38 kip. While not recommended as standard practice, but when needed, hold-down points may be staggered from 15” to 18” in order to facilitate the use of more draped strands and to minimize the hold-down force at an individual location. For additional information on draped strands, see Section 406-12.03. Semi-lightweight concrete may be used for this type of beam if it is economically justified. See Section 406-4.03. Lightweight concrete may be used for this type of beam if it is economically justified. See Section 406-4.03.

Prestressed-concrete bulb-tee members identified as wide bulb-tees have been approved for use. One of these sections should be considered if it is deemed to be more economical or structurally adequate than an Indiana bulb-tee member. See Figures 406-14AA through 406-14EE for details and section properties.

406-12.03 Strand Configuration, Mild-Steel Reinforcement, and Welded Wire Reinforcement [Rev. Sep. 2022]

406-12.03(01) General [Rev. Sep. 2022]

Mild reinforcing steel and welded wire reinforcement (WWR) should be detailed to allow its placement after the strands have been tensioned. If the reinforcement is a one-piece bar to be placed around the strands, it requires that the strands be threaded through the closed bars. By using two-piece bars that can be placed after the strand is tensioned, the fabrication process is simplified.

In specifying concrete cover and spacing of strands and bars, reinforcing-bar diameters and bend radii should be considered to avoid conflicts. Beam producers prefer to locate at least two strands in the top of each I-beam or bulb-tee beam below the top transverse bars and between the vertical legs of the web reinforcement to support the reinforcing-steel cage. This will also reduce the need for debonded strands.

406-12.03(02) Prestressing-Strands Configuration [Rev. Jun. 2021, Sep. 2022]

See Sections 406-13.0, 406-14.0, and 406-15.0 for typical strand patterns for standard prestressed beam sections. Other strand patterns may be used if there is a reason for deviation from the standard pattern, and the *LRFD* criteria for spacing and concrete cover are followed. If 11 strands are placed in a horizontal row in the bottom of a bulb-tee beam, the bending diagram for the vertical stirrup must be modified. The strand pattern shown may be used for nominal ½-in. or 0.6-in. diameter strands. Section 406-4.03 provides criteria for the strand diameters used.

The strand-pattern configurations shown in Sections 406-13.0, 406-14.0, and 406-15.0 were developed in accordance with the following.

1. Minimum center-to-center spacing of prestressing strands equal to 2 in.

2. Minimum concrete cover for prestressing strands should be 1½ in., which includes the modification factor of 0.8 for a water/cement ratio equal to or less than 0.40 as described in *LRFD* 5.10.1.

3. Minimum concrete cover to stirrups and confinement reinforcement should be 1 in.

The strand pattern has been configured so as to maximize the number of vertical rows of strands that can be draped. Due to the relatively thin top flange of a bulb-tee beam, strands placed in the top of the beam should be at least 6 in. from the outside edge of the flange.

406-12.03(03) Mild-Steel Reinforcement [Rev. Jun. 2021, Sep. 2022]

See Sections 406-13.0, 406-14.0, and 406-15.0 for typical mild-steel reinforcement configurations for the standard prestressed beam sections. The vertical shear reinforcement should consist of two legs of WWR whenever feasible. Each vertical leg of the WWR shear reinforcing should be anchored by a pair of longitudinal wires top and bottom in accordance with *LRFD*. In situations where the required number of strands can not be provided due to conflicts with the longitudinal wires, mild-steel stirrups may be used. For more details see Figures 406-13 A through 406-14EE. WWR should be ASTM A 1064 Grade 70. For WWR sizes, see Figure 405-2A. The maximum spacing of the vertical reinforcing should be in accordance with *LRFD* 5.7.2.6. U-shaped #4 bars should be placed at the top of the web and project into the deck to provide interface shear reinforcement. The maximum longitudinal spacing of reinforcement for interface shear transfer should be in accordance with *LRFD* 5.7.4.5.

A minimum of three horizontal U-shaped #4 bars should be placed in the web of each bulb-tee at the ends of the beam. See Section 406-14.0 for location and spacing of these bars. This reinforcement will help reduce the number and size of cracks, which can appear in the ends of the beams due to the prestress force. *LRFD* 5.9.4.4.1 requires that vertical reinforcement should be placed in the beam ends within a distance of one fourth of the member depth. This is to provide bursting resistance of the pretensioned anchorage zone. Enough reinforcing steel should be provided to resist not less than 4% of the prestress force at transfer. The end vertical bars should be as close to the ends of the beam as possible. The stress in the reinforcing steel should not exceed 20 ksi.

Confinement reinforcement in accordance with *LRFD* 5.9.4.4.2 should be placed in the bottom flange of each I-beam or bulb-tee as shown in Section 406-13.0 or 406-14.0, respectively. The reinforcement should be #3 bars spaced at 6 in. for a minimum distance of 1.5 times the depth of the member from the end of the beam or to the end of the strand debonding, whichever is greater.

406-12.04(02) Strands Released and Force Transferred to the Concrete [Rev. Sep. 2022]

The region near the end of the member does not receive the benefit of bending stresses due to dead load, and can develop tensile stresses in the top of the beam large enough to crack the concrete. The critical sections for computing the critical temporary stresses in the top of the beam should be near the end and at all debonding points. If the transfer length of the strands is chosen to be at the end of the beam and at the debonding points, the stress in the strands should be assumed to be zero at the end of the beam or debonding point, and should vary linearly to the full transfer of force to the concrete at the end of the strand transfer length.

The accepted methods to relieve excessive tensile stresses near the ends of the beam are as follows:

1. debonding, wherein the strands are kept straight but wrapped in plastic over a predetermined distance;

2. adding additional strands in the top of the beam, debonding them in the middle third, and releasing them at the center of the beam; or

3. draping some of the strands to reduce the strand eccentricity at the end of the beam.

When top strands have been designed with debonding near the middle of the beam, block-outs should be shown on the plans to allow for the required cutting of those strands.

406-12.05 Continuity for Superimposed Loads [Rev. Jun. 2021, Sep. 2022]

A multi-span bridge using composite beams should be made continuous for live load if possible. The design of the beams for a continuous structure is approximately the same as that for simple spans except that, in the area of negative moments, the member is treated as an ordinary reinforced-concrete section. The members should be assumed to be fully continuous with a constant moment of inertia in determining both the positive and negative moments due to superimposed loads.

Simply-supported beams should be made continuous by constructing a closure joint between the adjacent beam ends over the pier as part of the required concrete pier diaphragm, and to place extra longitudinal steel in the deck over the pier support to resist the negative moment.

Spans made continuous for live load are assumed to be treated as prestressed members in the positive-moment zone between supports, and as conventionally-reinforced members in the negative-moment zone over the support. The reinforcing steel in the deck should carry all of the tension in the composite section due to the negative moment. The longitudinal reinforcing steel in the deck that makes the girder continuous over an internal support should be designed in accordance with *LRFD* 5.12.3.3.8.

Continuity diaphragms may be designed in accordance with *LRFD* 5.12.3.3.10 based on the compressive strength of the precast girder regardless of the strength of the cast-in-place concrete.

No allowable tension limit is imposed on the top-fiber stresses of the beam in the negative-moment region. However, crack width, fatigue, and ultimate strength should be checked. If partial-depth precast, prestressed concrete stay-in-place forms are to be used, such as for an AASHTO I-beam superstructure, only the top mat of longitudinal steel reinforcement should be used to satisfy the negative-moment requirements.

406-12.06 Effect of Imposed Deformations [Rev. Jun. 2021, Sep. 2022]

Potential positive moments at the piers should also be considered in the design of a precast, prestressed-concrete beam structure made continuous for live load. Creep of the beams under the net effects of prestressing, self-weight, deck weight, and superimposed dead loads will tend to produce additional upward camber with time. Shrinkage of the deck concrete will tend to produce downward camber of the composite system with time. Loss of prestress due to creep, shrinkage, or relaxation will result in downward camber. Depending on the properties of the concrete materials and the age at which the beams are erected and subsequently made continuous, either positive or negative moments can occur over the continuous supports.

Where beams are made continuous at the relatively young age of less than 120 days from time of manufacture, it is more likely that positive moments will develop with time at the supports. These positive restraint moments are the result of the tendency of the beams to continue to camber upward as a result of ongoing creep strains associated with the transfer of prestress. Shrinkage of the concrete deck, loss of prestress, or creep strains due to self-weight, deck weight, or superimposed dead loads all have a tendency to reduce this positive moment.

Beams should be designed based on the assumption that they are cast no less than 28 days and no more than 60 days prior to pouring the deck. A note should be placed on the plans indicating the assumed beam casting date relative to the deck pour. For multi-span structures made continuous for live load, a time-dependent analysis should be made to predict the effects of positive restraining moments at the piers. However, the positive restraining effects should be ignored where they result in a less conservative design. The *PCI Bridge Design Manual*, Section 8.13.4.3, describes two methods to evaluate restraint moments at the piers. Positive-moment connections at the piers that have proven successful in the past should be used based on experience with similar spans and concrete-creep properties.

Unless positive-moment-connecting steel calculations are made, the minimum number of strands to be used for the positive-moment connection over the pier should be one-half the number of strands in the bottom row of the bottom flange of a bulb-tee or an I-beam. The minimum is 5 strands for a bulb-tee or I-beam type IV, 4 strands for an I-beam type II or III, or 3 strands for an I-beam type I.

The strands should be extended and bent up without the use of heat to make the positive moment connection. For a box beam, the minimum number of strands to be extended into the positive-moment connection and bent up should be 6 strands for a beam deeper than 27 in., or 4 strands for a beam depth equal to or less than 27 in.

The strands extended into the positive-moment connection between beams should not be debonded. The strands that are not used for the positive-moment connection should be trimmed back to the beam end to permit ease of beam and concrete placement.

The prestressing-strand and concrete strengths should be as shown in Section 406-4.0. The tensile and compressive stress limits should be as shown in *LRFD* 5.9.2.3. *LRFD* requires that only 80% of the live-load moment is to be applied in checking the tensile stress at service condition.

406-12.08 Segmental Construction [Rev. Sep. 2022]

Prestressed concrete beam lengths in the range of 100 ft to 120 ft are common. For a continuous structure, the girders are fabricated in lengths to span from support to support. A closure pour diaphragm is then made over the piers to provide continuity for live load and superimposed dead loads. This type of construction is cost effective because the girders can be erected in one piece without falsework. However, if girders are too long or too heavy to be shipped in lengths to accommodate the spans, spliced girders or segmental construction are options. Construction techniques have been developed that reduce the cost and can make concrete girders competitive with steel girders for spans in excess of 250 ft. The most commonly-used techniques are as follows:

1. segmental post-tensioned box girders erected on temporary falsework or by means of the balanced cantilever method; or

2. precast-concrete girders spliced at the construction site. These girders can either be supported on temporary falsework or spliced on the ground and lifted into place onto the supports.

Most spliced-girder bridges have bulb-tee beams with post-tensioning. Cambers, deflections, stresses, and end rotations of the structural components should be calculated during the stages of construction.

For further information, see publications of the Precast/Prestressed Concrete Institute, Post-Tensioning Institute, and the Segmental Concrete Bridge Institute.

406-12.09 Precast Beams Placed on Longitudinal Slope [Rev. Sep. 2022]

If the slope of the beam relative to the support surface is more than 1.0%, a tapered top plate will be required at the bearings. For tapered or flat top plate and sole plate details at end bents and piers see Figure 409-2D and Figure 409-7F.

406-14.0 INDIANA BULB-TEE BEAMS [Rev. Sep. 2022]

Figures 406-14AA through 406-14EE show details and section properties for these beams.

FIGURES

406-12 BB Embedded Plate [Del. Sep. 2022]

406-13 A I-Beam Type I [Rev. Sep. 2022]

406-13 B I-Beam Type II [Rev. Sep. 2022]

406-13 C I-Beam Type III [Rev. Sep. 2022]

406-13 D I-Beam Type IV [Rev. Sep. 2022]

406-14 AA Bulb-Tee Beam, 48" Top Flange [Add. Sep. 2022]

406-14 BB Wide Bulb-Tee Beam, 49" Top Flange [Add. Sep. 2022]

406-14 CC Bulb-Tee Beam, 60" Top Flange [Add. Sep. 2022]

406-14 DD Wide Bulb-Tee Beam, 61" Top Flange [Add. Sep. 2022]

406-14EE Bulb or Wide Bulb-Tee Beam Elevations Showing End Reinforcement [Add. Sep. 2022]