CHAPTER 405

Reinforced-Concrete Structure

Design Memorandum	Revision Date	Sections Affected
13-01	Jan. 2013	Figures 405-3F, -3G
17-08	Apr. 2017	405-1.02, 405-3.10
20-22	Oct. 2020	405-1.08 (new) and Figure 405-1D (new)
22-09	Jun. 2022	405-1.0, 4.05-1.01 through 4.05-1.07, 4.05- 1.08 (new), 405-2.0, 405-2.01 thru 405-2.07(02), 405-2.07(04) thru 405-2.10(02), 405-2.12, 405-3.0 thru 405-3.02, 405-3.04 thru 405-3.14, and Figures 405-1A, 405-1B,405-1C, 405-2C, 405-2CC, and 405-2D thru 405-2Y (deleted)

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CHAPTER 405

REINFORCED CONCRETE

The *LRFD Bridge Design Specifications* Section 5 specifies the design requirements for concrete in all structural elements. This Chapter provides supplementary information specifically regarding the general properties of concrete and reinforcing steel and the design of reinforced concrete.

References shown following section titles are to the AASHTO *LRFD Bridge Design Specifications*, hereafter referred to as *LRFD*.

405-1.0 GENERAL DESIGN CONSIDERATIONS [REV. JUN. 2022]

405-1.01 Material Properties

The minimum yield strength for reinforcing steel should be taken as 60 ksi.

Figure 405-1A provides criteria for concrete materials in structural elements.

405-1.02 Flexure [Rev. Apr. 2017, Jun. 2022]

Flexural design using the sectional model is appropriate for most girders, slabs, end bents, multi-column pier caps, and typical bridge components. The Strut-and-Tie Method (STM) may be considered for disturbed regions of typical bridge components and should be used for disturbed regions of hammerhead piers and other non-typical bridge components.

405-1.03 Limits for Reinforcing Steel [Rev. Jun. 2022]

The minimum reinforcement should be checked in accordance with *LRFD* 5.7.3.3.2 at a section to be certain that the amount of prestressed and non-prestressed reinforcement is enough to develop a factored flexural resistance, M_r, at least equal to the lesser of at least 1.2 times the cracking moment, M_{cr}, or 1.33 times the factored moment required by the applicable strength load combinations.

405-1.04 Shear and Torsion [Rev. Jun. 2022]

LRFD allows two methods of shear design for concrete, the strut-and-tie model and the sectional-design model. The sectional-design model is appropriate for the design of a typical bridge girder, slab, or other region of components where the assumptions of traditional beam theory are valid. This theory assumes that the response at a particular section depends only on the calculated values of the sectional force effects such as moment, shear, axial load, and torsion, but it does not consider the specific details of how the force effects were introduced into the member.

In a region near a discontinuity, such as an abrupt change in cross-section, opening, coped, or dapped end, deep beam, or corbel, the strut-and-tie model should be used. Torsion is most often not a major consideration for typical concrete bridge elements. Where torsion effects are present, the member should be designed in accordance with *LRFD*.

405-1.05 Strut-and-Tie Model [Rev. Jun. 2022]

The STM method has application for bridge components and parts such as hammerhead pier caps, dapped beam ends, post-tensioning anchorage zones, etc.

405-1.06 Fatigue [Rev. Jun. 2022]

The Fatigue Limit State should be investigated for the steel reinforcement or prestressing strands in accordance with *LRFD*.

405-1.07 Crack Control [Rev. Jun. 2022]

Crack-control design should be in accordance with *LRFD*. Class 1 exposure condition should be assumed for all components, including those exposed to typical amounts of deicing salts such as bridge decks. Class 2 exposure may be considered for unique projects where smaller crack widths are desired. A larger quantity of smaller and more closely spaced reinforcing bars are typically preferred over a fewer quantity of larger and more widely spaced reinforcing bars in regions where cracking is a significant concern.

405-1.08 Mass Concrete [Add. Oct. 2020]

Large volumes of concrete require special materials or placement procedures to limit thermal cracking and other risks associated with high heat of hydration. Concrete elements with least dimensions greater than 5 ft should be considered mass concrete and the designer should coordinate with the Office of Materials Management to develop a Unique Special Provision for mass pour requirements. Figure 405-1D, Mass Concrete, provides examples.

405-2.0 REINFORCING STEEL AND WELDED WIRE REINFORCING [REV. JUN. 2022]

405-2.01 Grade [Rev. Jun. 2022]

The yield strength of reinforcing bars should be taken as 60 ksi unless a project specific unique special provision allowing up to 75 ksi is approved by the Department. Deformed welded wire reinforcing, WWR, should only be detailed on the plans for the web reinforcing in prestressed AASHTO I-beam and bulb-tee beams, and the yield strength should be taken as 70 ksi. All other components should be detailed using reinforcing bars. Contractors may elect to substitute WWR for plan reinforcing bars in accordance with INDOT Standard Specifications Section 737. The modulus of elasticity, Es, should be taken as 29,000 ksi for reinforcing bars and WWR.

405-2.02 Sizes[Rev. Jun. 2022]

Reinforcing bars are referred to by number, and they vary in size from #3 to #18. WWR wires are referred to as the type, D for deformed and W for plain, followed by the hundredths of square inches of area. Figure 405-2A shows the sizes and properties of the types of bars and WWR used.

To avoid damage due to handling, the minimum bar size should be #4. Longitudinal ties in compression members may be #3. See Section 409-7.03(07).

405-2.03 Concrete Cover [Rev. Jun. 2022]

See Figure 405-2C for criteria for minimum concrete cover for various applications. The values shown in Figure 405-2C are based on $0.40 \leq w/c \leq 0.50$. All typical INDOT classes of concrete may be assumed to contain w/c ratios ≤ 0.50. All clearances to reinforcing steel shall be shown on the plans.

405-2.04 Spacing of Reinforcement [Rev. Jun. 2022]

For minimum spacing of bars, see *LRFD* 5.10.3.

Fit and clearance of reinforcement should be checked by means of calculations and large-scale drawings. Skews will tend to aggravate problems of reinforcing fit. Tolerances normally allowed for cutting, bending, and locating reinforcement should be considered.

The distance from the face of concrete to the center of the first bar should be shown. Where the distance between the first and last bars is such that the number of bars required results in spacings that are not to the nearer of ¼ in., the bars should be shown to be equally spaced. Alternatively, one odd spacing may be used with spacings that are to the nearer of ¼ in.

405-2.05 Fabrication Lengths [Rev. Jun. 2022]

See Figure 405-2A for maximum and normal bar lengths for fabrication. The maximum length of bars extending above a horizontal joint, e.g., from a footing into a wall, should be 10 ft.

405-2.06 Development of Reinforcement [Rev. Jun. 2022]

Development of reinforcement should be as described in *LRFD* 5.10.8.2.

405-2.06(01) Development Length in Tension [Rev. Jun. 2022]

Development length, l_d, or anchorage of reinforcement, is required on both sides of a point of maximum stress at each section of a member.

Development of bars in tension involves calculating the basic development length, l_{db}, which is modified by factors to reflect bar spacing, cover, enclosing transverse reinforcement, top-bar effect, type of aggregate, epoxy coating, and the ratio of required area to provide the area of reinforcement to be developed.

405-2.06(02) Development Length in Compression [Rev. Jun. 2022]

The standard procedure is to use tension development lengths for bars in either tension or in compression. This ensures that an adequate development length will be provided in a compression member that will be primarily controlled by bending.

405-2.06(03) Standard End Hook Development Length in Tension [Rev. Jun. 2022]

A standard end hook, utilizing a 90-deg or 180-deg bend, is used to develop a bar in tension where space limitations restrict the use of a straight bar. End hooks on compression bars are not effective for development-length purposes.

405-2.07 Splices [Rev. Jun. 2022]

Splice-length determination should be as described in *LRFD* 5.10.8.4.

405-2.07(01) General [Rev. Jun. 2022]

Lap splices or mechanical splices can be used to splice reinforcing bars: Lap splicing is the most common method. The plans should show the locations and lengths of all lap splices. Due to splice lengths required, lap splices are not permitted for #11 bars or larger. However, if #11 bars or larger are necessary, mechanical bar splices should be used. Mechanical splices should also be considered in lieu of lap splices in a highly congested area.

If transverse reinforcing steel in a bridge deck is to be lapped near a longitudinal construction joint, the entire lap splice should be located on the side of the construction joint that will be poured last. The difference in elevation between the previously poured portion of the deck and the cambered subsequent phase should be considered when evaluating the constructability of the splice.

405-2.07(02) Lap Splices in Tension [Rev. Jun. 2022]

Many of the same factors which affect development length affect splices. Consequently, tension lap splices are a function of the bar development length, l_d.

For a tension splice, the length of a lap splice between bars of different sizes should be governed by the smaller bar, and the area of the smaller bar should be assumed for design within the lap length.

405-2.07(03) Lap Splices in Compression

Lap splices in a compression member should be sized for tension lap splices. The design of a compression member, such as a column, pier wall, or abutment wall, involves the combination of vertical and lateral loads. Therefore, the policy of requiring a tension lap splice accounts for the possibility that the member design is primarily controlled by bending. Also, the increase in cost of additional splice-reinforcement material is small.

405-2.07(04) Mechanical Splices [Rev. Jun. 2022]

A mechanical splice is a system that transfers tension from one bar to another without relying on the surrounding concrete. Mechanical splices should only be used where required by *LRFD*, or locations where lap splices aren't feasible due to space constraints.

405-2.07(05) Welded Splices

Splicing of reinforcing bars by means of welding is not permitted.

405-2.08 Hooks and Bends [Rev. Jun. 2022]

Standard hooks, seismic hooks, and minimum bend diameters should be in accordance with *LRFD* and the CRSI *Manual of Standard Practice.* Dimensions and bend diameters of non-standard hooks shall be shown on the plans. The total length of each bent bar should be rounded up to the next 1 in. Bend deductions do not need to be considered in the total bar length.

405-2.09 Epoxy-Coated Reinforcement [Rev. Jun. 2022]

Epoxy-coated reinforcement should be used at the following locations:

1. the bridge deck;
2. a reinforced-concrete slab bridge;
3. the end bents and wingwalls of an integral end bent beam and deck-type structure;
4. the end bents and wingwalls of a beam and deck-type structure where deck expansion joints are located at the ends of the structure;
5. above the footing of each interior substructure unit that is located below a deck expansion joint. For a tall pier or piers located in close proximity of roads that receive deicing salts, engineering judgment should be used;
6. concrete bridge railing;
7. bars extending into the deck from the beams or substructure; or
8. reinforced-concrete bridge approaches.

For all other locations, uncoated bars are acceptable. These include the following:

1. piers, bents, or abutments other than those listed above; or
2. a reinforced-concrete retaining wall.

405-2.10 Reinforcement Detailing [Rev. Jun. 2022]

405-2.10(01) Standard Practice[Rev. Jun. 2022]

The following provides the standard practice for detailing reinforcing bars.

1. Reinforcing bars should be called out in the plan, elevation, and section views to indicate the size, location, and spacing of the individual bars. The number of reinforcing bars should be called out in only one view, usually the plan or elevation view. In other views, only the bar size and length, or bar mark, should be called out.

2. In a plan or elevation view, only the first bar and the last bar of a series of bars should be drawn, and the number of bars indicated between. In a section view, all bars should be shown.

3. All dimensions on details are measured on centerlines of bars, except where cover, e.g., 2 in. cl., is indicated.

4. Straight bars should be designated by size and length, e.g., #4 x 15'-0".

5. Straight-bars that include laps within the overall run should be detailed in 3-in. multiples. Where the required end clearance will restrain the overall length of individual bars, the length should be detailed to the nearest inch.

6. Bent bars are assigned a bar mark of which the first one or two numbers indicate the size of the bar, and the last two numbers, 01 to 99, indicate the mark. Each bar mark may be assigned a lower-case-letter suffix to indicate the location of the bar in the proper element of the structure (e.g., 801a, 802a). The following letters may be used as suffixes:

   a, b, c, d, f, h, k, m, n, p, r, s, t, u, v, w, x, y, and z.

7. Epoxy-coated bars should be suffixed by the letter E (e.g., #6E x 15'-0", 801aE). If all bars are epoxy-coated, a note will suffice.

The following should be considered when selecting and detailing reinforcing steel.

1. Where possible, similar bar lengths and shapes should be repeated to result in as few different bars in a structural element as practical.

2. Consideration should be given to ease of placement of bars. A bar should not have to be threaded through a maze of other bars. The bars should be located so that they can be easily supported or tied to other reinforcement.

3. It may be more constructible to lap two bent bars than to have a bar with multiple bends.

405-2.10(02) Bars in Section [Rev. Jun. 2022]

Figure 405-2Z provides a section through a hypothetical member showing some of the accepted methods for detailing reinforcing steel. The following list describes some of the concerns and observations that should be considered in detailing reinforcing steel.

A section view should be drawn to a large-enough scale to show reinforcing details.

1. Stirrups or other bars not shown end-on should be drawn as single broken or unbroken lines for a scale smaller than 1:10, or as double unbroken lines for a scale of 1:10 or larger.

2. Bends of standard hooks and stirrups need not be dimensioned. However, all bends should be drawn to scale.

3. Bars shown end-on should be shown as small circles. The circles may be left open or may be shown as a dot. However, the symbol used should be consistently applied on the drawing. If bars and holes will be shown on the same view, the bars should be shown as solid dots.

4. An arrowhead pointing to the bar or a circle drawn around the bar are the acceptable methods of detailing for a bar shown end-on. An arrowhead should point directly to the bar.

5. Sections cut at specific locations along a member are preferred to a typical section for a complex reinforcing pattern.

6. Corner bars enclosed by stirrups or ties should be shown at the corner of the bend (see Figure 405-2Z).

405-2.11 Bending Diagrams

The following is the standard practice for detailing bending diagrams.

1. All dimensions are measured out-to-out of bars.
2. All bent-bar partial dimensions should be shown to the nearer ¼ in.
3. The overall length of a bent bar should be rounded up to the next 1 in.

See Figure 405-2AA for information on bending diagrams.

405-2.12 Cutting Diagrams [Rev. Jun. 2022]

Two methods of showing cutting diagrams are provided. Other methods may be used at the discretion of the designer. The first is used where two sets of the same size bars are required and the second is used where only one bar of each size is required. Cutting diagrams are given a bar mark similar to bent bars. The first method shown in Figure 405-2BB is an example of a skewed deck with the same bars in the top and bottom mats. The pertinent information should be determined as follows:

1. Determine the longest, *B*, and shortest, *A*, bars required to the nearer 1 in.
2. Determine the number of bars required.
3. Divide the difference in length between the longest and shortest bars by the number of spaces (the number of bars minus 1) to obtain the increment. The number of bars is the total required after the bars have been cut. For example, if there are 20 bars in the cutting group then there will be 40 total bars required. Length is measured to the nearest inch and increment is measured to the nearest eighth of an inch.

$$Increment = \frac{(B - A)}{(N - 1)}$$

N = Number of Bars (In cutting group prior to cutting)

4. The length *L* is the sum of *A* + *B*.

The second method should be used where only one bar of each length is required, such as in an asymmetric widening of a hammerhead pier. An even number of bars will be provided by this cutting group. Figure 405-2CC shows the cantilevered portion of a hammerhead pier.

1. Determine the longest, *A*, and shortest, *D*, bars required to the nearer 1 in.
2. Determine the number of bars required.
3. Divide the difference in length between the longest and shortest bars by the number of spaces (the number of bars minus 1) to obtain the increment. The number of bars is the total required after the bars have been cut. For example, if there are 20 bars in the cutting group then there will be 40 total bars produced after cutting. Length is measured to the nearest inch and increment is measured to the nearest eighth of an inch.

$$Increment = \frac{(A - D)}{(2N - 1)}$$

N = Number of Bars (In cutting group prior to cutting)

4. Determine dimensions *B* and *C* as follows:

$$B\ or\ C = \frac{A+D}{2} \pm 0.5(Increment)$$

5. The length $L = A + D = B + C$. Adjust dimensions as necessary to make them fit this equation.

405-2.13 Bill of Materials

The following applies to the Bill of Materials.

1. The bars should be listed in descending order of size.
2. For each bar size, bent bars should be listed sequentially by number first followed by straight bars.
3. Straight bars should be listed in descending order of length.
4. Subtotals of the weight should be provided for each bar size.
5. Plain and epoxy-coated bars should be billed separately with totals for each.
6. There should be a separate Bill of Materials shown on the appropriate plan sheet for each structural element.
7. If two structural elements are very similar in dimension and reinforcement, it is permissible to combine the quantities into one Bill of Materials.

Figure 405-2DD illustrates a typical Bill of Materials for a reinforced-concrete bridge approach.

405-3.0 REINFORCED CAST-IN-PLACE CONCRETE SLAB SUPERSTRUCTURE [REV. JUN. 2022]

405-3.01 General [Rev. Jun. 2022]

The reinforced cast-in-place concrete slab superstructure is frequently used due to its suitability for short spans and long-term durability. It is the simplest among all superstructure systems.

405-3.01(01) Materials [Rev. Jun. 2022]

Class C concrete and epoxy coated reinforcing bars should be used.

405-3.01(02) Cover [Rev. Jun. 2022]

LRFD and Figure 405-2C provides criteria for minimum concrete cover for all structure elements. All clearances to reinforcing steel should be shown on the plans.

405-3.01(03) Haunches [Rev. Jun. 2022]

Straight haunches are preferred to parabolic haunches because straight haunches are relatively easy to form yet result in relatively proper stress flow.

Haunching is used to decrease maximum positive moments in a continuous structure by attracting more-negative moments to the haunches and to provide adequate resistance at the haunches for the increased negative moments. It is a simple, effective, and economical way to enhance the resistance of a thin concrete slab. As illustrated in Figure 405-3A, there are three ways of forming the haunch. The parabolic shape shown in detail (a) is the most natural in terms of stress flow. The parabolic haunch, however, is not the easiest to form and, as alternatives, the straight haunch shown in detail (b), and the drop panel shown in detail (c), should be considered where appropriate. Constant thickness slabs with cap beams at the interior supports are the easier to form and construct, and should be considered where haunches aren't necessary for an efficient design.

Figure 405-3B depicts the elevation and plan of a three-span, continuous haunched slab bridge with an extensive skew. The preferable ratio between interior and end span is approximately 1.25 to 1.33 for economy, but the superstructure type allows considerable freedom in selecting the span ratio. The ratio between the depths at the centerlines of the interior piers and at the point of maximum positive moment should be between 2.0 and 2.5. Except for aesthetics, the length of the haunch need not exceed the kL value indicated in Figure 405-3A, where L is the end span length. Longer haunches may be unnecessarily expensive or structurally counterproductive.

405-3.01(04) Substructures [Rev. Jun. 2022]

The following describes the practice for types of substructures used.

1. End Supports. Where possible, integral end bents should be used. See Chapter 409 for more information.

2. Interior Supports. See Chapter 402 for practices regarding the selection of the type of interior support (e.g., piers, frame bents).

405-3.01(05) Minimum Reinforcement [Rev. Jun. 2022]

In both the longitudinal and transverse directions, at both the top and bottom of the slab, the minimum reinforcement should be determined in accordance with *LRFD*

According to *LRFD*, bottom transverse reinforcement may be determined either by means of a two-dimensional analysis or as a percentage of the maximum longitudinal positive moment steel. For a heavily skewed or curved bridge, the analytical approach is recommended.

405-3.02 Computation of Slab Dead-Load Deflections [Rev. Jun. 2022]

For a concrete-deck-on-girder-type superstructure, the screed elevations should be provided in accordance with *LRFD* and Chapter 404. For a simple span or a continuous-spans reinforced-concrete slab superstructure, a dead-load deflection diagram showing the quarter-point deflections should be shown on the plans. The contractor uses this information to develop screed elevations that will place the concrete slab at the proper final elevations after falsework removal. If a concrete-slab superstructure is located within a superelevation transition, or if other geometric complications are present, screed elevations are to be provided at 5-ft intervals.

The following criteria should be used in developing a dead-load deflection diagram.

1. Compute dead-load deflections due to the weight of the concrete slab at the span quarter points or at a closer spacing if more accuracy is desired.
2. Compute instantaneous deflections by the usual methods using formulas for elastic deflections.
3. For determining deflections, use the gross moment of inertia.
4. Round off deflections values to the nearer 0.1 in.
5. The deflection of the concrete slab caused by the weight of a concrete railing is insignificant and may be ignored in developing the slab dead-load deflection diagram.
6. Do not include the effects of form settlement or crushing. This is the contractor's responsibility.

405-3.03 Construction Joints

Transverse construction joints are not permitted. The INDOT *Standard Specifications* provide construction requirements where transverse construction joints are unavoidable if concrete placement is interrupted due to rain or other unavoidable event.

Longitudinal construction joints are also undesirable. However, the method of placing concrete, rate of delivery of concrete, and the type of finishing machine used by the contractor dictate whether or not a slab must be placed in one or more placements. An optional longitudinal keyway construction joint shall be shown on the plans at the centerline of roadway. The contractor may request permission to eliminate the construction joint by providing information specific to the proposed method of placing concrete and equipment to be used.

Where phased construction is not anticipated, transverse reinforcing steel may be lapped at the optional longitudinal construction joint. If the structure will be built in phases, show the entire lap splices for all transverse reinforcing steel on the side of the construction joint that will be placed last.

405-3.04 Longitudinal Edge-Beam Design [Rev. Jun. 2022]

An edge beam must be provided along each slab edge. Bridge railings should not be considered in edge beam design. An edge beam should be detailed as a more heavily-reinforced portion of the slab. The width of the edge beam may be taken to be the width of the equivalent strip as specified in *LRFD*.

405-3.05 Shrinkage and Temperature Reinforcement [Rev. Jun. 2022]

Shrinkage and temperature reinforcement should in designed in accordance with *LRFD*. Evaluating the redistribution of force effects as a result of shrinkage, temperature change, creep, and movements of supports is not necessary.

405-3.06 Reinforcing Steel and Constructibility [Rev. Jun. 2022]

The following practices for reinforcing-steel placement should be considered to improve the constructability.

1. The maximum reinforcing-bar size should be #11.
2. The minimum spacing of reinforcing bars should preferably be 6 in.
3. Longitudinal steel should be detailed in a 2-bar alternating pattern, with one of the bars continuous through the slab. The maximum size difference should be two standard bar sizes.

405-3.07 Drainage Outlets [Rev. Jun. 2022]

LRFD and Chapter 202 discuss the hydrological and hydraulic analyses for a bridge deck. The following specifically applies to inlet selection.

The deck drains shown on the INDOT *Standard Drawings* should be specified whenever feasible. The deck drains are designed for a reinforced-concrete slab bridge only. The drain is a PVC pipe, 6 in. dia., set into the deck, as shown on the INDOT *Standard Drawings*. The small deck drains have limited hydraulic capacity. Therefore, the standard spacing is approximately 6 ft.

A 1/2-in. depression, which extends 12 in. transversely from the face of the curb, slightly increases the capacity. The PVC pipe must clear the bent-cap face by 2 ft.

405-3.08 Distribution of Concrete-Railing Dead Load [Rev. Jun. 2022]

Dead load due to barrier railings placed after the deck has set, should be distributed with 60% of the load applied to the edge beam and 40% of the load applied to the interior strip. The slab should also be checked with the railing loads distributed equally across the full width.

405-3.09 Shear Resistance [Rev. Jun. 2022]

Slabs designed for flexure in accordance with *LRFD* may be considered satisfactory for shear.

405-3.10 Minimum Thickness of Slab [Rev. Apr. 2017, Jun. 2022]

The typical minimum slab thickness should be in accordance with *LRFD*. In using the equations in the *LRFD* Table, the assumptions are as follows.

1. *S* is the length of the longest span.
2. The calculated thickness includes the 1/2-in. sacrificial wearing surface.
3. The thickness obtained from the table should be used as a general guideline. The final design thickness may vary from the typical minimum depths provided all other design criteria are satisfied.

405-3.11 Development of Flexural Reinforcement [Rev. Jun. 2022]

LRFD provides requirements for flexural reinforcement that must be extended beyond the point where it is no longer needed. Similarly, there are requirements for the maximum amount of reinforcing that may be terminated at a section.

405-3.12 Skewed Reinforced-Concrete Slab Bridge [Rev. Jun. 2022]

For a skew angle of less than 25 deg, the transverse reinforcement is permitted to be parallel to the skew, providing for equal bar lengths. For a skew angle of 25 deg or greater, the transverse reinforcement should be placed perpendicular to the longitudinal reinforcement.

Special slab-superstructure design or modifications to the integral end supports are not required for a greatly-skewed or -curved structure. The requirements are based upon performance of relatively small span structures constructed to date. Such slab superstructures have included skews in excess of 50 deg and moderate curvatures. A significant deviation from successful past practice should be reviewed.

405-3.13 Transverse Shrinkage and Temperature Reinforcement in the Top of the Slab at the Bent Caps [Rev. Jun. 2022]

Top longitudinal cap flexural reinforcement cannot be considered effective reinforcement for transverse shrinkage and temperature stresses described in *LRFD* if this steel is located significantly below the surface of the concrete slab.

405-3.14 Fatigue-Limit State [Rev. Jun. 2022]

The design should be as described in *LRFD* 5.5.3.

Concrete	Compressive Strength, f_c' (psi)
Class C	4000
Class A	3500
Class B	3000

Notes:

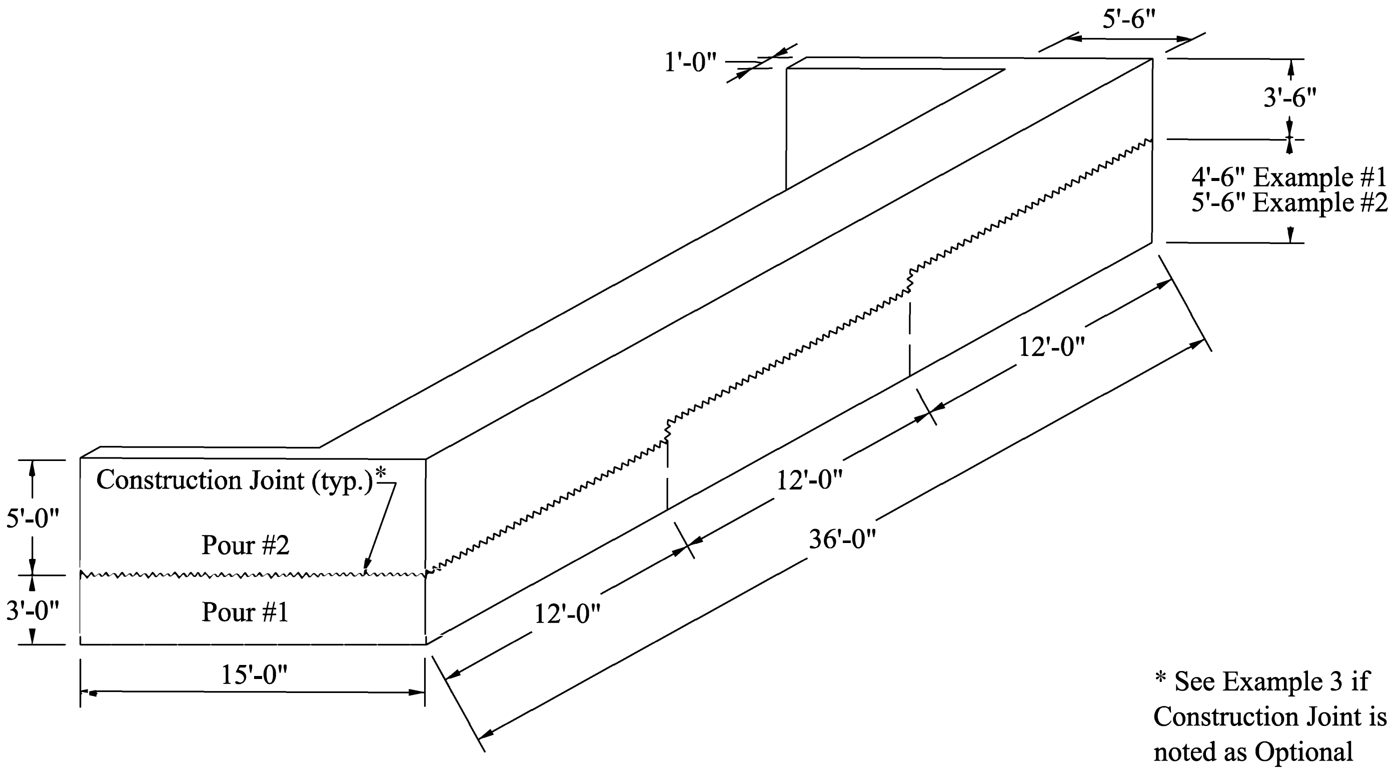
1. *Normal-weight-concrete density* = *150 lb/ft*^{3} *for computing loads*
   = *145 lb/ft*^{3} *for computing properties*
2. *Material properties for concrete should be determined in accordance with AASHTO LRFD Bridge Design Specifications*

MATERIAL PROPERTIES OF CONCRETE

Figure 405-1A

405-1B Strut-and-Tie Model for Hammerhead Pier [Del. Apr. 2022]

405-1C Strut-and-Tie Model for Beam Ends [Del. Apr. 2022]



INTEGRAL END BENT ISOMETRIC VIEW

MASS CONCRETE DEFINITION - EXAMPLES

EXAMPLE #1: The portion of Pour #1 with the largest least dimension is the tallest step in the end bent cap, with dimensions of 4'-6" x 5'-6" x 12'-0". Since the least dimension of 4'-6" is less than or equal to 5'-0", Pour #1 would not be considered mass concrete. The portion of Pour #2 with the largest least dimension is above the lowest step in the end bent cap, with dimensions of 5'-0" x 5'-6" x 12'-0". Since the least dimension of 5'-0" is equal to the limit of 5'-0", Pour #2 would not be considered mass concrete. Therefore, this end bent would not be considered mass concrete.

EXAMPLE #2: The portion of Pour #1 with the largest least dimension is the tallest step in the end bent cap, with dimensions of 5'-6" x 5'-6" x 12'-0". Since the least dimension of 5'-6" is greater than 5'-0", Pour #1 would be considered mass concrete. Therefore, this end bent would be considered mass concrete and the Designer should coordinate with the Office of Materials Management to develop a Unique Special Provision for mass pour requirements.

EXAMPLE 3#: Using the dimensions shown in Example #1, assume the Construction Joint between Pour #1 and Pour #2 has been noted as "Optional" on the plans. The Contractor may elect to place both pours at the same time, which would result in a least concrete dimension of 5'-6" x 8'-0" x 12'-0". Therefore, this end bent would need to be considered mass concrete due to the potential for a single pour with a least dimension greater than 5'-0", and the Designer should coordinate with the Office of Materials Management to develop a Unique Special Provision for mass pour requirements, should the Contractor elect to omit the optional construction joint.

MASS CONCRETE

Figure 405-1D

[New December 2021]

Bar-Size Designation	WWR Wire Size**	Reinforcing Bar Nominal Dimensions ***			Maximum Bar Length for Fabrication (ft)	Preferred Maximum Bar Length for Detailing (ft)
		Weight (lb/ft)	Diameter (in)	Area (in^2)		
#3*	D11.0	0.376	0.375	0.11	35	30
#4*	D20.0	0.668	0.500	0.20	45	40
#5	D31.0	1.043	0.625	0.31	45	40
#6	D44.0	1.502	0.750	0.44	45	40
#7	N/A	2.044	0.875	0.60	45	40
#8		2.670	1.000	0.79	45	40
#9		3.400	1.128	1.00	45	40
#10		4.303	1.270	1.27	45	40
#11		5.313	1.410	1.56	45	40
#14		7.650	1.693	2.25	45	40
#18		13.600	2.257	4.00	45	40

**Maximum bar length does not apply to spiral bars.*
***Deformed Wire should be used. Plain wire may be used where allowed by LFRD.*
****Nominal weight and diameter of WWR vary slightly from the equivalent reinforcing bar size.*

REINFORCING-BAR AND WELDED WIRE REINFORCING (WWR) SIZES

Figure 405-2A

405-2B Reinforcing Bars, Areas (in2) Per One Foot Section

Item	Cover (in.)
Deck or Reinforced-Concrete Slab:	
Top Bars	2½ *
Bottom Bars	1
Ends of Slab	2
Faces of Copings	2
Footing:	
General	3
Bottom Bars Cast Against Earth	4
All Other Structural Elements	2

** Includes a ½-in. sacrificial wearing surface to account for future milling and overlay*

Notes:

1. Concrete cover should be in accordance with AASHTO LFRD Bridge Design Specifications unless specifically addressed in the Indiana Design Manual.
2. See Chapter 406 for concrete cover for prestressed-concrete beams.

MINIMUM CONCRETE COVER (in.)
FOR DESIGN AND DETAILING

Figure 405-2C

405-2D Minimum Center-to-Center Spacing of Bars [Del. Apr. 2022]

405-2E Development Lengths for Uncoated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2F Development Lengths for Uncoated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2G Development Lengths for Epoxy Coated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2H Development Lengths for Epoxy Coated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2 I Hooked Uncoated Bar Development Lengths, Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2J Hooked Uncoated Bar Development Lengths, Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2K Hooked Epoxy Coated Bar Development Lengths, Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2L Hooked Epoxy Coated Bar Development Lengths, Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2M Class A Splice Lengths for Uncoated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2N Class A Splice Lengths for Uncoated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2O Class A Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2P Class A Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2Q Class B Splice Lengths for Uncoated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2R Class B Splice Lengths for Uncoated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2S Class B Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2TClass B Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2U Class C Splice Lengths for Uncoated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2V Class C Splice Lengths for Uncoated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

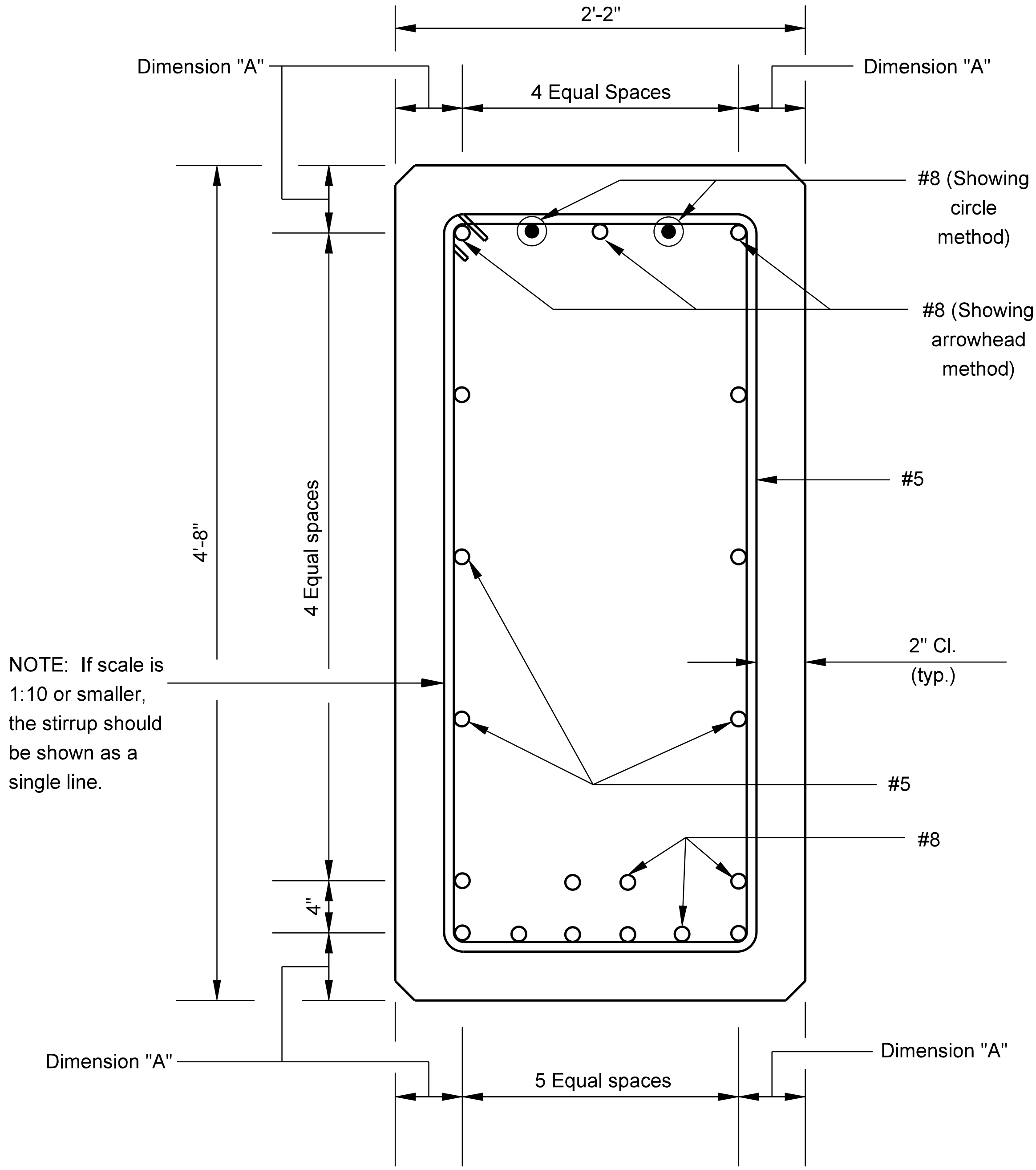
405-2W Class C Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 3 ksi [Del. Apr. 2022]

405-2X Class C Splice Lengths for Epoxy Coated Bars in Tension, f_c' = 4 ksi [Del. Apr. 2022]

405-2Y Hooks and Bends [Del. Apr. 2022]

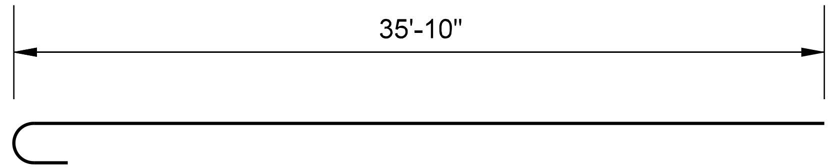
COVER — 2"
STIRRUP — 5/8"
½ BAR ϕ — 1/2"
ALLOWANCE FOR STIRRUP BEND — 1/4"

DIMENSION "A" = 3 3/8" (Min.)
= 3 1/2" (Rounded for constructibility)



BARS IN SECTION
Figure 405-2Z

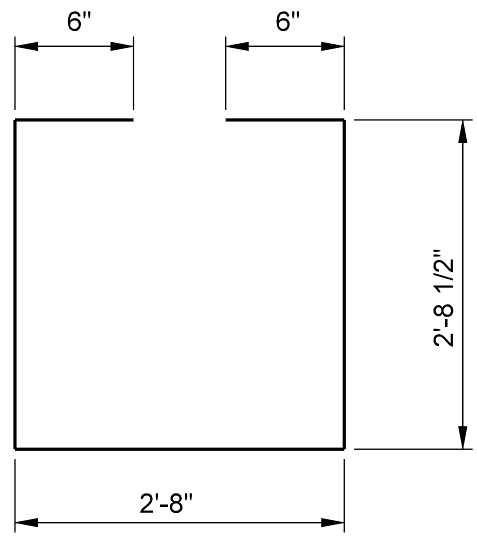
EXAMPLE NO. 1 (Longitudinal Bar)



35'-10"
11" (180° HOOK)
36'-9"

802c X 36'-9"

EXAMPLE NO. 2 (Stirrup)

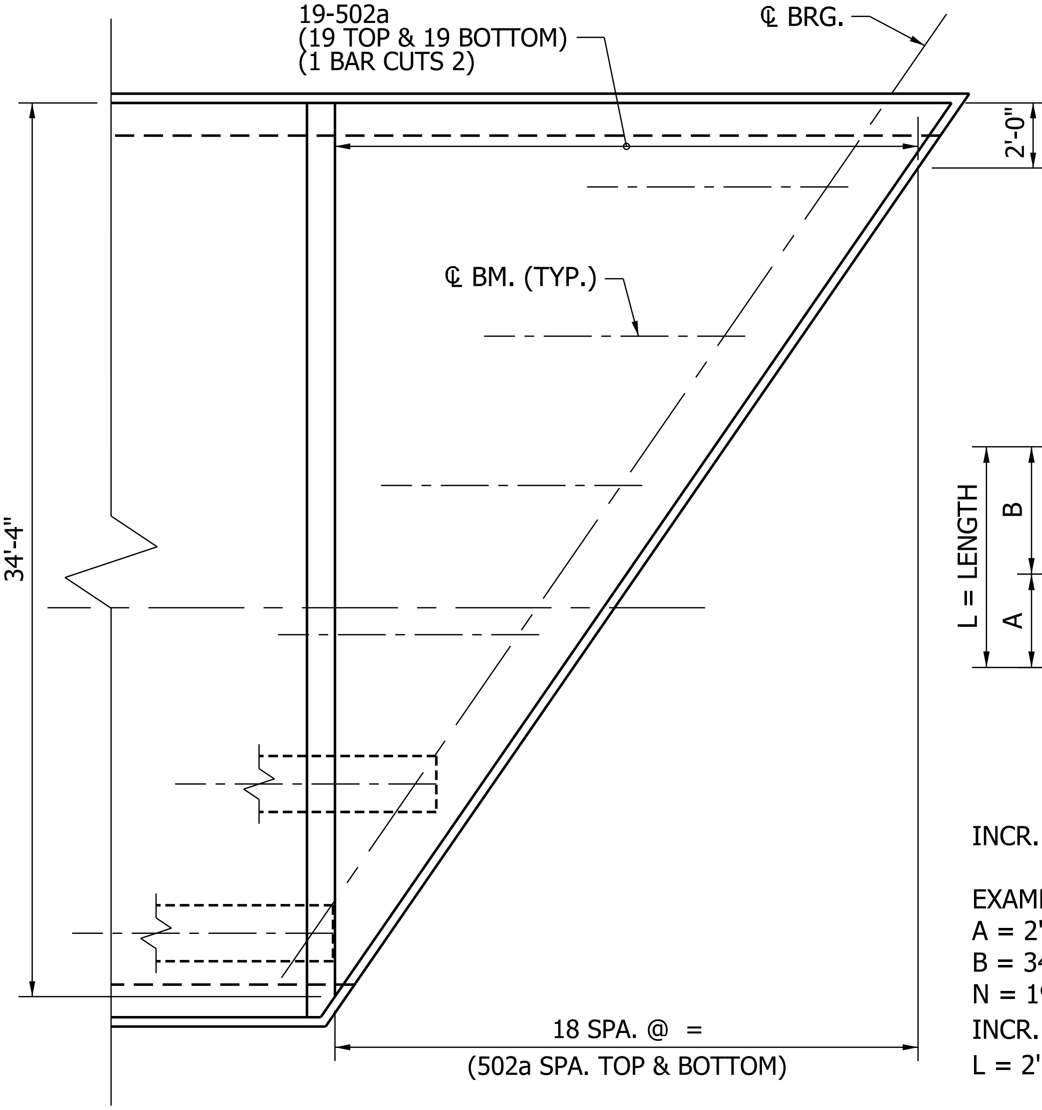


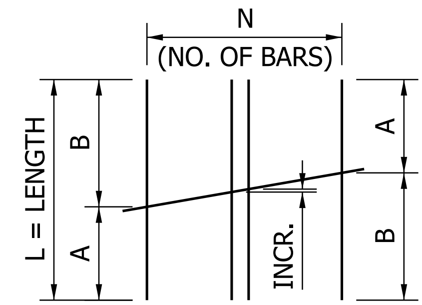
2'-8 1/2"
2'-8 1/2"
2'-8"
6" (90° HOOK)
6" (90° HOOK)
9'-1"

502c X 9'-1"

BENDING DIAGRAM EXAMPLES

Figure 405-2AA





CUTTING DIAGRAM
(1 BAR CUTS 2)
502a X L

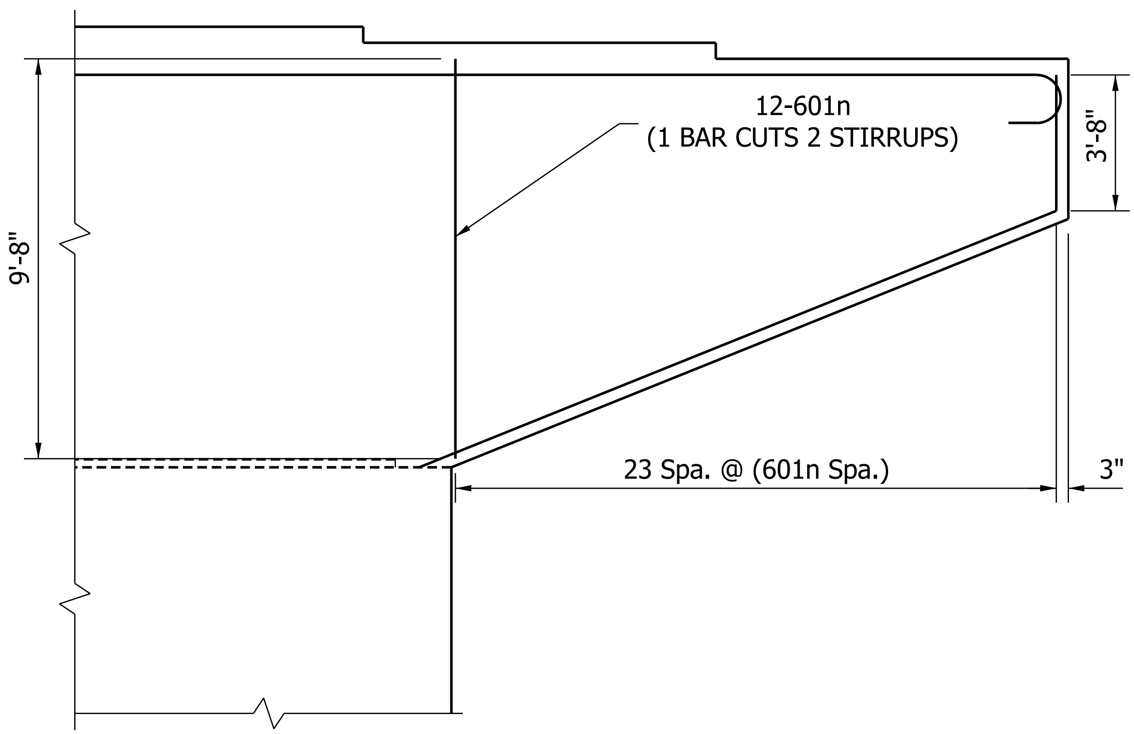
INCR. = (B - A) / (N - 1)

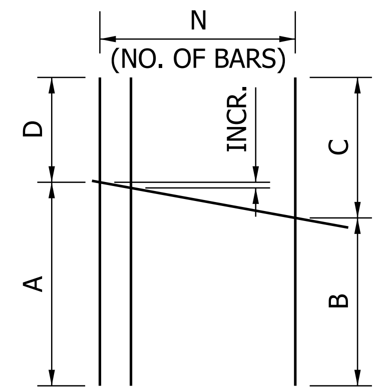
EXAMPLE:
A = 2'-0"
B = 34'-4"
N = 19
INCR. = (34'-4" - 2'-0") / (19 - 1) = 1'-9½"
L = 2'-0" + 34'-4" = 36'-4"

THIS CUTTING DIAGRAM WILL GENERATE 38 TOTAL 502a BARS, HALF OF WHICH WILL BE THE SAME LENGTH (19 TOP, 19 BOTTOM)

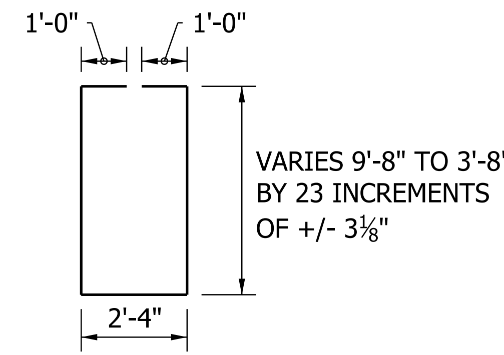
CUTTING DIAGRAM
(Transverse Steel in Bridge Deck)

Figure 405-2BB





INCR. = (A - D) / (2N - 1)
CUTTING DIAGRAM



EXAMPLE BENDING DIAGRAM

601n X 35'-4"
(1 BAR CUTS 2 STIRRUPS)

EXAMPLE:
Ht. A = 9'-8"
Ht. D = 3'-8"
N = (24 Bars after cutting) / 2 = 12 Bars in cutting group
Ht. INCR. = (9'-8" - 3'-8") / (2 x 12 - 1) = 0.2609' = $3\frac{1}{8}$"
Ht. B = (9'-8" + 3'-8") / 2 + 0.2609' / 2 = 6'-$9\frac{1}{2}$"
Ht. C = (9'-8" = 3'-8") / 2 - 0.2609' / 2 = 6'-$6\frac{3}{8}$"

A =2'-4" + 2 x (9'-8" + 1'-0") = 23'-8"
D =2'-4" + 2 x (3'-8" + 1'-0") = 11'-8"
B =2'-4" + 2 x (6'-$9\frac{1}{2}$" + 1'-0") = 17'-11"
C =2'-4" + 2 x (6'-$6\frac{3}{8}$" + 1'-0") = 17'-$4\frac{3}{4}$"
L = 23'-8" + 11'-8" = 35'-4"

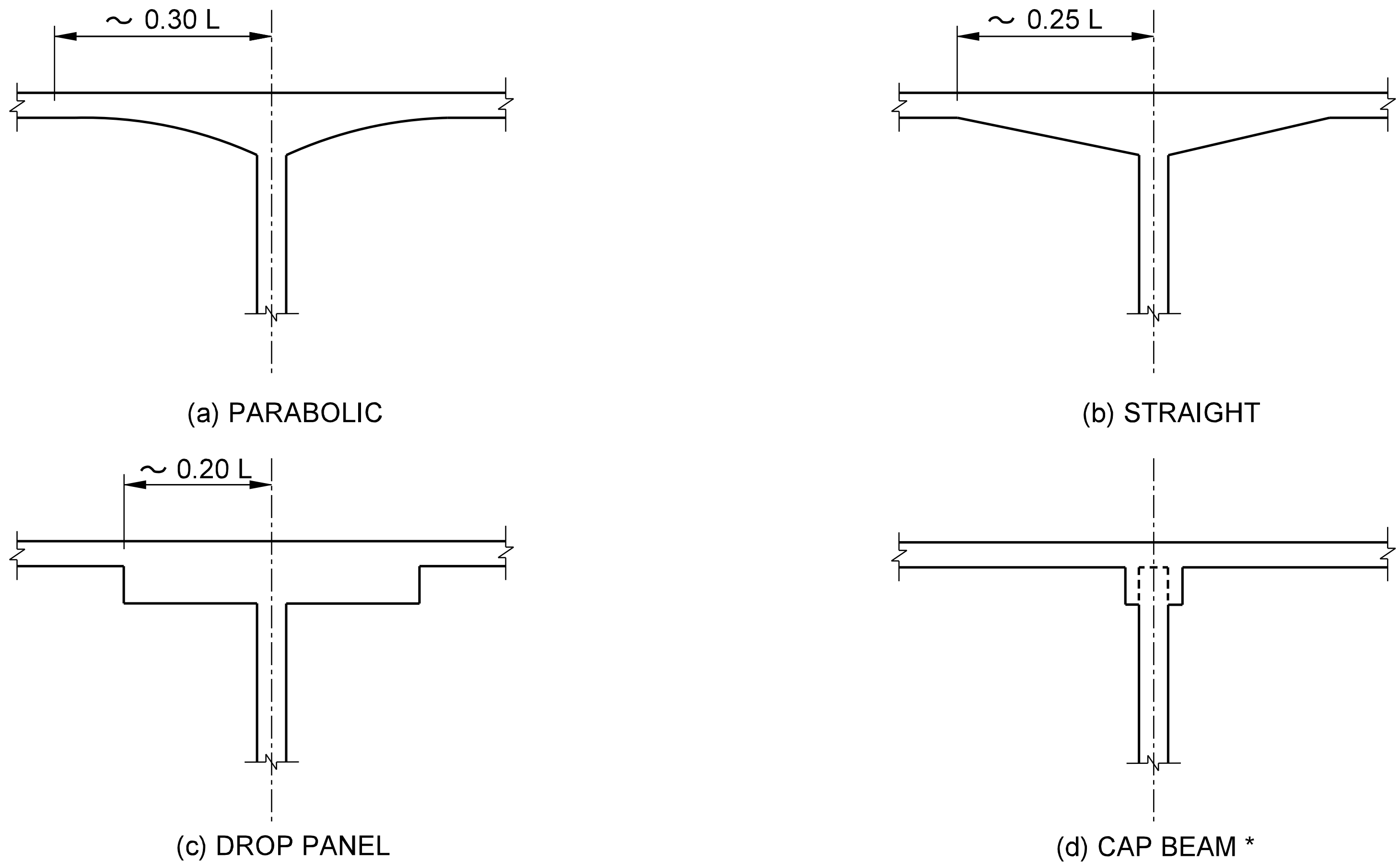
CUTTING DIAGRAM
(Hammerhead Stem Pier)

Figure 405-2CC

<table>
<tr><th colspan="4">BILL OF MATERIALS</th></tr>
<tr><th colspan="4">R.C. BRIDGE APPROACH
BENT NO. 1
(BENT NO. 6 SAME)</th></tr>
<tr><th colspan="4">EPOXY COATED REINFORCING BARS</th></tr>
<tr><th>Size or Mark</th><th>No. of Bars</th><th>Length</th><th>Weight (Lbs)</th></tr>
<tr><td>501s</td><td>88</td><td>20' - 9"</td><td></td></tr>
<tr><td>502s</td><td>4</td><td>16' - 1"</td><td></td></tr>
<tr><td>#5</td><td>32</td><td>46' - 0"</td><td></td></tr>
<tr><td>#5</td><td>10</td><td>43' - 8"</td><td></td></tr>
<tr><td>#5</td><td>66</td><td>20' - 2"</td><td></td></tr>
<tr><td>#5</td><td>4</td><td>15' - 6"</td><td></td></tr>
<tr><td colspan="3">Total #5 Bars</td><td>5,416</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="3">Total Epoxy Coated Reinforcing Bars</td><td>5,416</td></tr>
<tr><td colspan="4"></td></tr>
<tr><th colspan="4">MISCELLANEOUS</th></tr>
<tr><td colspan="3">Reinf. Concr. Bridge Approach, 12"</td><td>105 Sys</td></tr>
<tr><td colspan="3">Subbase for PCCP</td><td>26.5 Cys</td></tr>
<tr><td colspan="3">Subgrade Treatment, Type IC</td><td>85 Sys</td></tr>
<tr><td colspan="3">Geotextile for Subgrade, Type 2B</td><td>105 Sys</td></tr>
<tr><td colspan="3">Terminal Joint, Type HMA</td><td>44 Lft</td></tr>
<tr><td colspan="3">Pre-Compressed Foam Joint</td><td>44 Lft</td></tr>
</table>

REINFORCED-CONCRETE BRIDGE APPROACH BILL OF MATERIALS

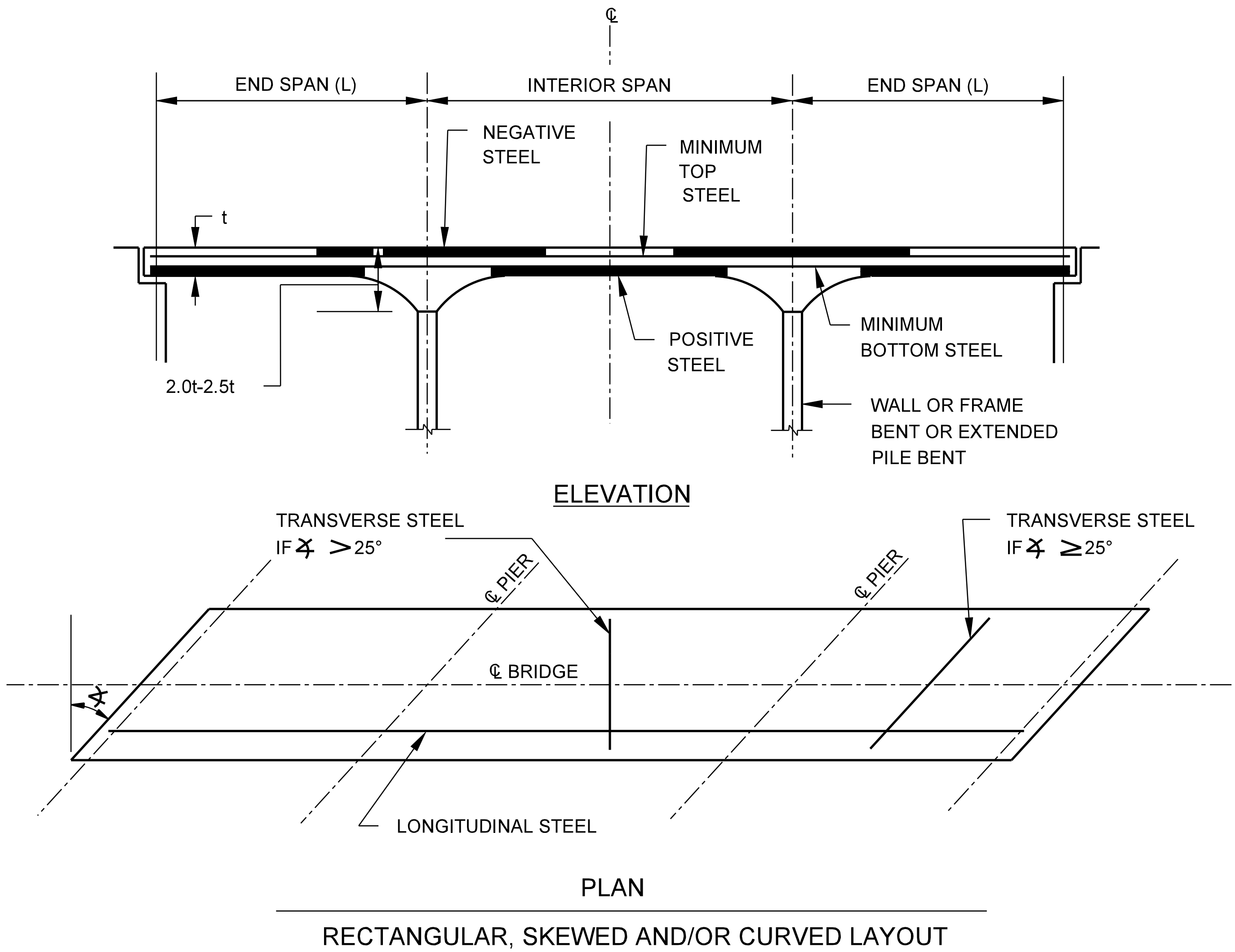
Figure 405-2DD



* THIS CONFIGURATION SHOULD NOT BE USED AS A STRUCTURAL HAUNCH

HAUNCH CONFIGURATIONS FOR REINFORCED CONCRETE SLAB SUPERTRUCTURES

Figure 405-3A

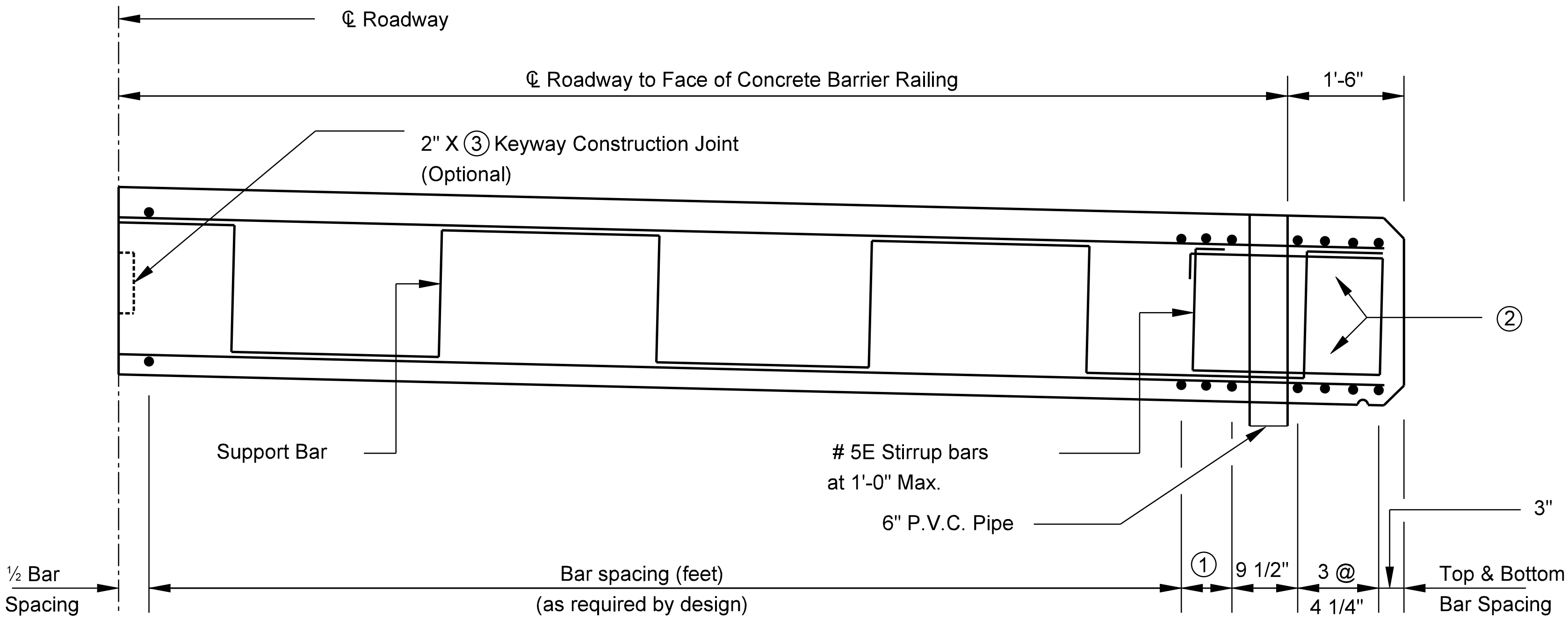


TYPICAL REINFORCED CONCRETE SLAB SUPERSTRUCTURE

Figure 405-3B

405-3C Shrinkage and Temperature Reinforcement for Slab Superstructure

NOTE: Entire typical section to be detailed on plans.



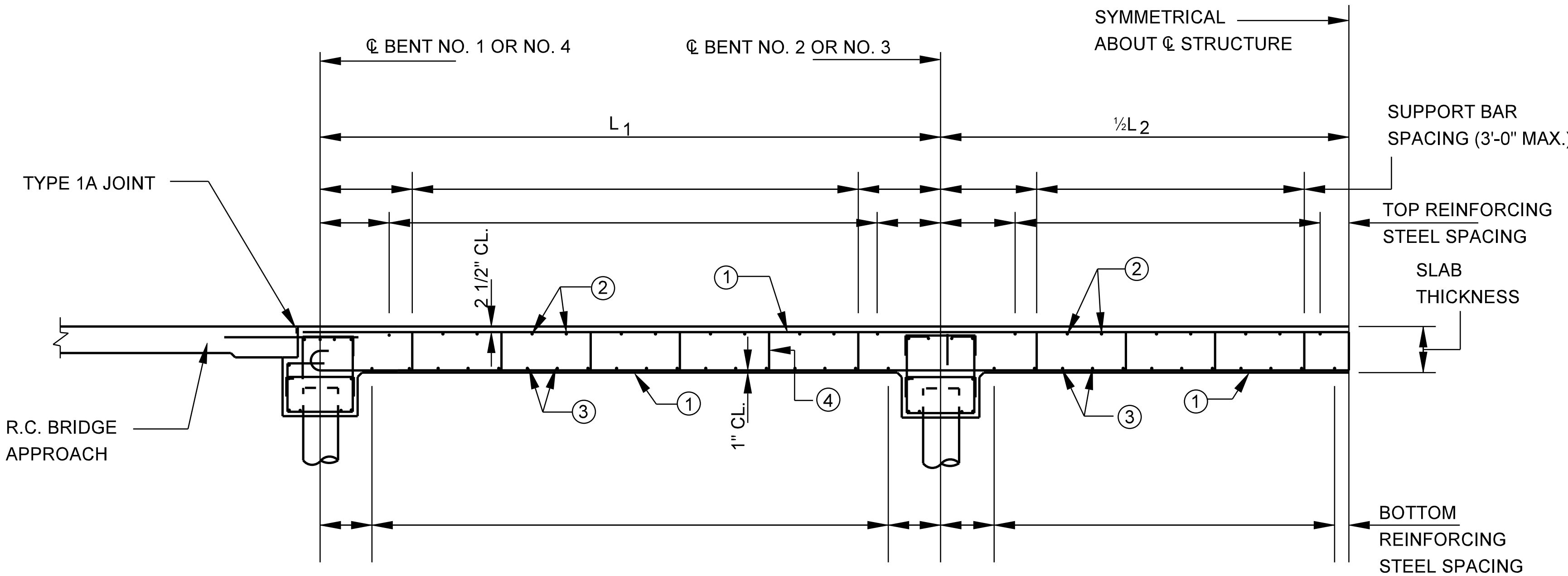
① Bar spacing and number of spaces to be determined to facilitate a constant bar spacing in remainder of slab.

② Design edge beam in accordance with articles in the LRFD Specifications, but use as a minimum the same area of steel per foot as in slab.

③ For depth of keyway, use on-third the slab thickness.

INTEGRAL CAP AT SLAB SUPERSTRUCTURE
(Typical Half-Section)

Figure 405-3D



(1) LONGITUDINAL BARS AS REQUIRED FOR DESIGN.

(2) SHRINKAGE AND TEMPERATURE REINFORCEMENT

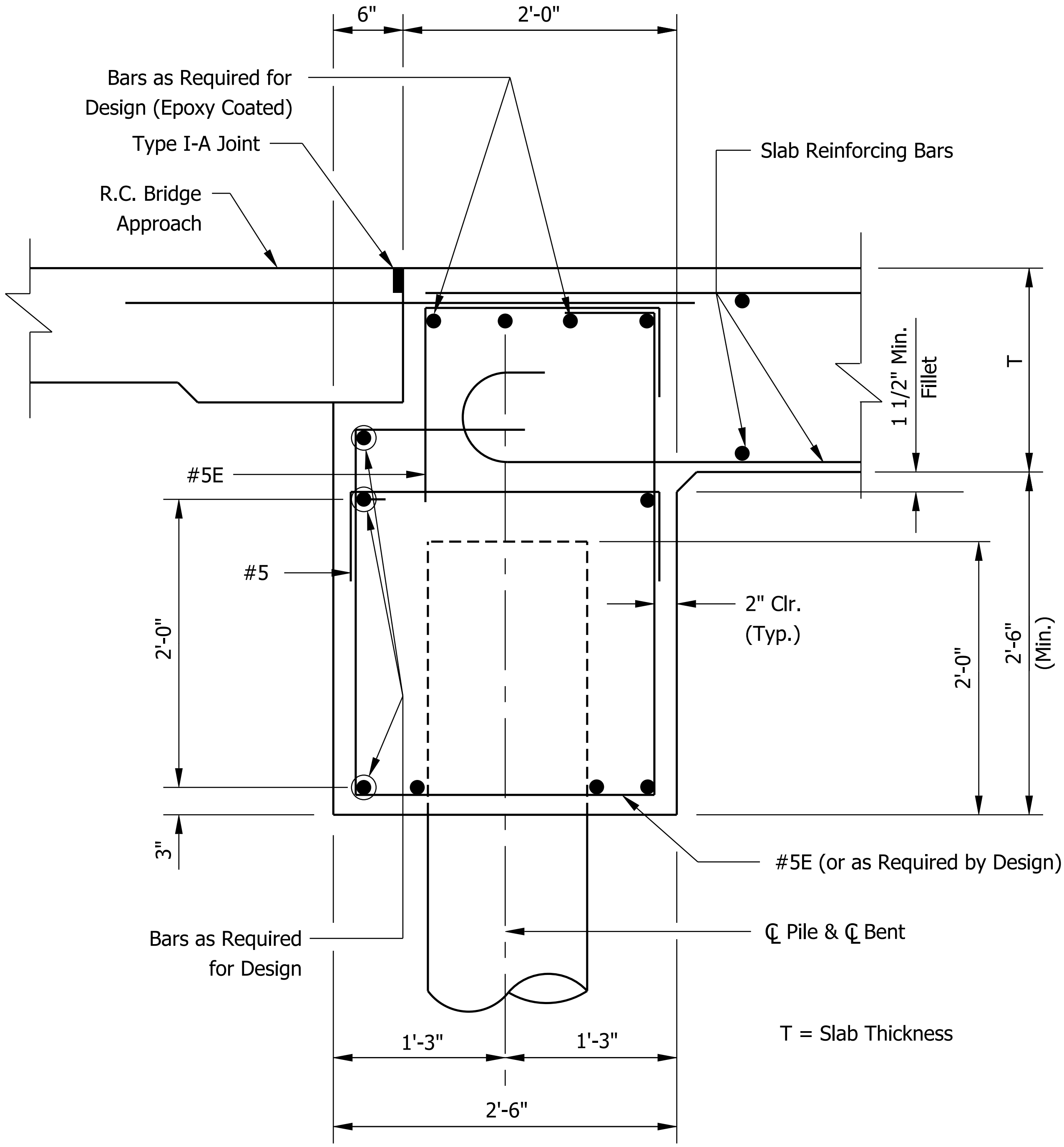
(3) DISTRIBUTION REINFORCEMENT

(4) SUPPORT BARS (MAX. SPACING 3'-0")

LONGITUDINAL STEEL BAR SIZE	SUPPORT BAR SIZE
# 6 OR 7	# 5
# 8	# 6
# 9	# 6
# 10 OR LARGER	# 7

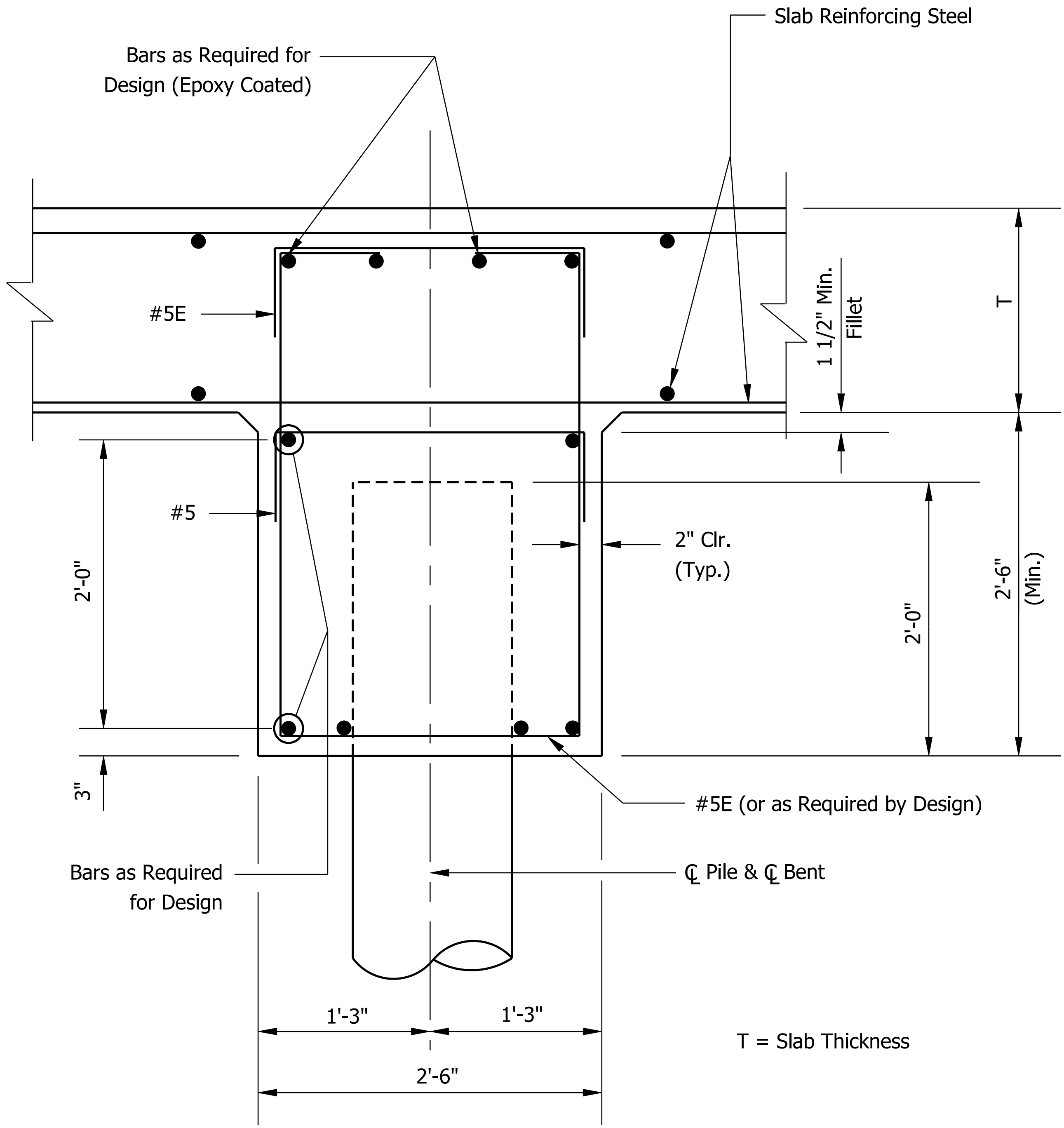
INTEGRAL CAPS AT SLAB SUPERSTRUCTURE
(Half Longitudinal Section)

Figure 405-3E



INTEGRAL CAP AT SLAB SUPERSTRUCTURE
(Section Through End Bent)

Figure 405-3F



INTEGRAL CAP AT SLAB SUPERSTRUCTURE
(Section Through Interior Bent)

Figure 405-3G