

CHAPTER 406

Prestressed-Concrete Structure

NOTE: References to material in 2011 Design Manual have been highlighted in blue throughout this document.

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CHAPTER 406

PRESTRESSED CONCRETE

406-1.0 GENERAL

The requirements of this Chapter will apply to each bridge designed with normal or lightweight concrete reinforced with prestressed or post-tensioned strands. Partial prestressing is not permitted. The requirements described herein are based on a 28-day concrete strength, f'_c , of 4 to 10 ksi.

406-2.0 DEFINITIONS

See *LRFD* 5.2.

406-3.0 NOTATIONS

See *LRFD* 5.3.

406-4.0 MATERIAL PROPERTIES

406-4.01 General

The material properties cited herein are based on the construction materials specified in *LRFD* 5.4. The minimum acceptable properties and test procedures shall be specified in the contract documents.

406-4.02 Normal-Weight and Semi-Lightweight Concrete

The minimum f'_c for prestressed or post-tensioned concrete components shall be shown on the plans. Such a strength outside the range shown in [Section 406-1.0](#) is not permitted without written approval of the Director of Bridges. For lightweight concrete, the air dry unit weight shall be shown on the plans. See *LRFD* 5.4.2.2 for the coefficient of linear expansion.

The following will apply to concrete.

1. The design compressive strength of normal-weight concrete at 28 days, f'_c , shall 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 Bridges.

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

406-4.02(01) Shrinkage and Creep

Losses due to shrinkage and creep, for other than than a segmentally-constructed bridge, that require a more-precise estimate including specific materials, structural dimensions, site conditions, construction methods, and age at various stages of erection, can be estimated by means of the methods specified in *LRFD* 5.4.2.3.2 and 5.4.2.3.3. Other acceptable methods are those described in the CEB-FIP 1978 / 1990 code. The annual average ambient relative humidity shall be taken as 70%.

406-4.02(02) Modulus of Elasticity, Poisson's Ratio, and Modulus of Rupture

The modulus of elasticity shall be calculated as specified in *LRFD* Eqn. 5.4.2.4-1. Poisson's ratio shall be taken as 0.2. See *LRFD* 5.4.2.6 for modulus-of-rupture values depending on whether the concrete is normal weight or lightweight, and whether the intended application is control of cracking, deflection, camber, or shear resistance.

406-4.03 Semi-Lightweight Concrete

Normal-weight concrete has a unit weight between 135 lb/ft³ and 160 lb/ft³. The use of semi-lightweight concrete, with normal-weight sand mixed with lightweight coarse aggregate, is permitted with a specified density between 120 lb/ft³ and 130 lb/ft³. Other unit weights may be used if approved by the Director of Bridges. The use of semi-lightweight concrete shall be demonstrated to be necessary and cost effective during the structure-size-and-type study.

The structural performance of this concrete is equal to that of normal-weight concrete. However, the potential problems that shall be addressed are the control of the water content in the lightweight aggregate and the frost-sensitivity of lightweight aggregate for a period of two weeks after casting. Consideration shall be given to using the mix-design procedures for lightweight concrete described in ACI 211.2.

The modulus of elasticity will be less than that for normal-weight concrete. Creep, shrinkage, and deflection shall be appropriately evaluated and accounted for if semi-lightweight concrete is to be used. The formula shown in *LRFD* 5.4.2.6 shall be used in lieu of physical test values for modulus of rupture. The formula for sand-lightweight concrete shall be used for semi-lightweight concrete.

406-4.04 Prestressing Steel

Prestressing strands shall 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 shall be used.

1. Nominal 3/8 in., $A_s = 0.085 \text{ in}^2$, for use in a stay-in-place deck panel.
2. Nominal 1/2 in., $A_s = 0.167 \text{ in}^2$, for use in an I, bulb-tee, or box beam, or post-tensioned member.
3. Nominal 0.6 in., $A_s = 0.217 \text{ in}^2$, 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.

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

406-4.05 Post-Tensioning Anchorage and Couplers

See *LRFD* 5.4.5 regarding the use of anchorages or couplers. Tendons, anchorages, end fittings, and couplers shall be protected against corrosion. If couplers are used to connect bars, they shall be enclosed in duct housings long enough to permit the necessary movement.

406-4.06 Ducts

See *LRFD* 5.4.6 for types of ducts, radius-of-curvature limits, general considerations for tendons, and size requirements. Polyethylene ducts shall be used in a corrosive environment such as in a bridge deck or in a substructure element under a joint. The contract documents shall indicate the type of duct material to be used.

Ducts for a post-tensioned bulb-tee beam shall be of round, semi-rigid, galvanized-metal. The wall thickness shall not be less than 28 gage. A radius that requires prebending shall be avoided if possible.

If the bridge is to be constructed by means of post-tensioning precast components together longitudinally or transversely by use of a cast-in-place concrete joint, the end of each duct shall be extended beyond the concrete interface for not less than 3 in. and not more than 6 in. to facilitate joining the ducts. If necessary, the extension can be in a local breakout at the concrete interface. Joints between sections of ducts shall be positive metallic connections, which do not result in angle changes at the joints.

The plans shall show all pertinent geometry required for development of working drawings with the correct tendon alignment in both elevation and plan views. This includes anchorage regions and areas where there are tight or reverse curvatures of the the tendons.

Curved ducts that run parallel to each other or around a void or re-entrant corner shall be encased in concrete and reinforced as necessary to avoid radial failure, or pullout into another duct or void.

Upon completion of post-tensioning, the ducts shall be grouted.

Ducts or anchorage assemblies for post-tensioning shall be provided with a pipe or other suitable connection at each end for the injection of grout after prestressing. A duct of over 200 ft in length shall be in accordance with the recommendations of the PTI. Vents shall be ½-in. minimum diameter standard pipe or suitable plastic pipe. Connections to the ducts shall be made with metallic or plastic fasteners. Plastic components, if selected and approved, shall not react with the concrete or enhance corrosion of the prestressing steel, and shall be free of water-soluble chlorides. The vents shall be mortar tight, taped as necessary, and shall provide means for injection of grout through the vents and for positive sealing of the vents. Ends of steel vents shall be removed at least 1 in. below the concrete deck surface, if appropriate, after the grout has set. Ends of plastic vents shall be removed to the surface of the concrete after the grout has set. Grout injection pipes shall be fitted with positive mechanical shut-off valves. Vents and ejection pipes shall be fitted with valves. Caps shall not be removed or opened until the grout has set.

406-5.0 LIMIT STATES

406-5.01 General

In addition to service, fatigue, strength, and extreme-event limit states, prestressed or post-tensioned components shall be investigated for stresses and deformations for each critical stage during construction, stressing, handling, transportation, and erection.

406-5.02 Service-Limit State

See *LRFD* 5.7.3.4 for control of cracking, 5.7.3.6 for deformations, and 5.9.4 for stress limits for concrete.

406-5.03 Fatigue-Limit State

See *LRFD* 5.5.3.1 to determine if fatigue shall be considered. Use the stress ranges for prestressing tendons provided in *LRFD* 5.5.3.3 if necessary.

406-5.04 Strength-Limit State

See *LRFD* 5.5.4.2 and Table 5.5.4.2.2-1 for resistance factors for tension-controlled, compression-controlled, or transition prestressed concrete sections, shear, torsion, or anchorage zones. For segmental construction, the resistance factors shall be modified for flexure and shear accordingly. See *LRFD* 5.5.4.3 for required stability checks.

406-5.05 Extreme-Event-Limit State

See *LRFD* 5.4.6.2 and Table 3.4.1-1.

406-6.0 DESIGN CONSIDERATIONS, FLEXURE AND AXIAL FORCE EFFECTS

See *LRFD* 5.6.3 and 5.10.9.4 for a strut-and-tie model overview that can be used in the design of an anchorage zone, deep beam, bracket, or corbel.

The assumptions for service, fatigue, strength, and extreme-event-limit states are described in *LRFD* 5.7.1. Strength equations provided in *LRFD* 5.7.2 are based on the rectangular-stress-block approach.

For stress calculations in prestressing steel at nominal flexure resistance, the equations for components with bonded and unbonded tendons provided in *LRFD* 5.7.3.1.1 and 5.7.3.1.2 are acceptable. For components with both bonded and unbonded tendons, the simplified analysis provided in *LRFD* 5.7.3.1.3b is acceptable.

The flexural resistance may be computed with the equations provided in *LRFD* 5.7.3.2, or a more-precise calculation can be used as described in *LRFD* 5.7.3.2.5.

The amount of prestressed tensile reinforcement is limited by the minimum reinforcement requirements provided in *LRFD* 5.7.3.3.2. There is not a limitation in *LRFD* 5.7.4.2 for maximum prestressed tensile reinforcement for flexural members. For compression members, the maximum and minimum reinforcement requirements provided in *LRFD* 5.7.4.3 are applicable. Slenderness effects, computation of factored axial resistance, and biaxial flexure effects provided in *LRFD* 5.7.4.4 are applicable to prestressed concrete columns.

Instantaneous deflections, long-term deflections, and cambers shall be computed with the modulus of elasticity, moment of inertia, and cracking moment specified in *LRFD* 5.7.3.6.2. The methods provided therein to obtain long term deflections from instantaneous deflections are acceptable.

406-7.0 SHEAR AND TORSION

406-7.01 General

LRFD 5.6.3 allows the strut-and-tie model and the sectional-design model for shear design of prestressed concrete. In a region near a discontinuity, the strut-and-tie model shall be used. The sectional-design model is appropriate for the design of a girder, slab, or other region of components where the assumptions of traditional beam theory are valid. See *LRFD* 5.8.3 and *PCI Bridge Design Manual* Section 8.12 for more information regarding the strut-and-tie model.

Torsional effects shall be investigated only if the condition in *LRFD* 5.8.2.1 for normal weight concrete, or slightly modified for lightweight concrete, is satisfied. If necessary, the torsional resistance obtained with the sectional-design model is provided in *LRFD* 5.8.2.2.

Transverse reinforcement, minimum and maximum requirements, types of transverse reinforcement, and shear stresses of concrete are provided in *LRFD* 5.8.2.4. They shall be satisfied in the design. These are complemented by *LRFD* 5.8.2.9 for a segmental post-tensioned concrete box-girder bridge.

406-7.02 Sectional-Design Model

LRFD 5.8.3 discusses the sectional-design model. The general formulas used to calculate the nominal shear resistance are shown in *LRFD* 5.8.3.3-1. The parameters used to evaluate these expressions depend on the adopted approach. For a prestressed-concrete structure, the use of either the modified-compression field theory or the simplified procedure is acceptable.

In order to account for the tension caused by shear, the longitudinal-reinforcement requirements shown in *LRFD* 5.8.3.6.3 shall be satisfied for sections subjected to combined shear and torsion.

406-7.03 Interface Shear Transfer – Shear Friction

A cast-in-place concrete deck designed to act compositely with precast-concrete beams shall be able to resist the horizontal shearing forces at the interface between the two elements. *LRFD* 5.8.4.1 discusses the requirements for shear transfer. The nominal shear resistance of the interface and the factored interface shear force are provided in *LRFD* 5.8.4.2. The most appropriate condition of the interaction between concrete-slab and concrete-girder surfaces shall be selected individually from the six situations of cohesion and friction factors provided in *LRFD* 5.8.4.3. The requirement for minimum area of interface shear reinforcement provided in *LRFD* 5.8.4.4 shall be satisfied.

406-7.04 Segmental Concrete Bridge

LRFD 5.8.5 states that principal stresses determined using classic beam theory and the principles of Mohr's circle and local tensions in the web from anchorage of tendons shall be investigated. The principal tensile stress shall not exceed the tensile stress limits shown in *LRFD* Table 5.9.4.2.2-1.

The shear and torsion requirements shown in *LRFD* 5.8.3.6 supersede those for the design of a segmental post-tensioned concrete box girder bridge. *LRFD* 5.8.2 applies, but with the modifications shown in *LRFD* 5.8.3 through 5.8.5.

406-8.0 PRESTRESSED CONCRETE

406-8.01 General Considerations and Stress Limitations

General requirements for design, concrete strength, buckling, section properties, crack control, location of tendon relative to the duct, and stresses due to imposed deformations are provided in

LRFD 5.9.1. Contrary to the *LRFD* requirements, INDOT does not allow a transformed section for a pretensioned member.

The stress limitations for prestressing tendons, deformed high-strength bars, and concrete before and after losses have occurred, are provided in *LRFD* 5.9.3.

406-8.02 Loss of Prestress

Total prestress losses in a member constructed and prestressed in a single stage are provided in *LRFD* 5.9.5.1. The losses are defined as instantaneous losses such as anchorage set, friction, elastic shortening, and time-dependent losses. The acceptable methods provided for determining the time-dependent losses are an approximate and a refined method. The refined method can be used for the final design of a nonsegmental prestressed concrete member. For a post-tensioned concrete member with multistage construction or prestressing, the prestress losses shall be computed by means of a time-dependent-analysis method such as that described in CEB-FIP (1978 / 1990). The approximate lump-sum estimate method shall be used for preliminary design only.

The values of the wobble and curvature friction coefficients, and the anchor-set loss assumed for the design shall be shown on the plans.

406-9.0 PRESTRESSING-REINFORCEMENT REQUIREMENTS

406-9.01 Spacing of Prestressing Tendons and Ducts

The minimum and maximum spacing of pretensioned strands, and curved and straight post-tensioning ducts in the horizontal plane are provided in *LRFD* 5.10.3.3. However, bundling of ducts will not be permitted. *LRFD* 5.10.3.5 provides requirements for longitudinal post-tensioning couplers.

406-9.02 Tendon Confinement and Effects of Curved Tendons

LRFD 5.10.4 provides general requirements for tendon confinement, and in-plane and out-of-plane force effects. Shear resistance of the concrete cover against pullout shall be satisfied, or fully-anchored tiebacks shall be provided. Local confining reinforcement shall be provided if out-of-plane forces exceed the factored shear resistance of concrete cover. *LRFD* 5.10.5 provides the maximum unsupported length of external tendons.

406-9.03 Post-Tensioned and Pretensioned Anchorage Zone

LRFD 5.10.9 provides general requirements for the anchorage zones at the end and intermediate anchorages. Requirements for design of general zones are provided in *LRFD* 5.10.9.3. The strut-and-tie, elastic stress analysis, and approximate method are acceptable. The design requirements for a local zone including special anchorage devices are provided in *LRFD* 5.10.9.7. For a pretensioned anchorage zone, *LRFD* 5.10.10 shall be followed.

406-10.0 DEVELOPMENT OF PRESTRESSING STRANDS AND DEBONDING

The transfer length of pretensioned components is shown in *LRFD* 5.11.4.1. The specific requirements for development length and variation of pretensioned stress in strands for bonded or debonded strands are provided in *LRFD* 5.11.4.2 and 5.11.4.3. 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 shall be debonded. The allowable percentage of debonded strands for an AASHTO I-beam or a box beam shall 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 shall not be included in the percentages shown above.
2. Exterior strands in each horizontal row shall not be debonded.
3. Bonded and debonded strands shall preferably alternate both vertically and horizontally.
4. Debonding termination points shall 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, shall be terminated at one point.

See *LRFD* 5.11.4.3 for additional guidelines.

6. Two strands shall 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 shall 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. The top strands may not need to be cut if ultimate moment controls the number of strands in the bottom flange.

7. Top strands in a concrete box beam shall 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* 5.12.

406-11.0 DIAPHRAGMS

Design considerations for diaphragms are provided in *LRFD* 5.13.2.2.

406-11.01 General Requirements

A multi-girder bridge, except for one with adjacent box beams, shall have diaphragms provided at the abutments, end bents, and interior piers or bents, to resist lateral forces and transmit loads to points of support. For certain span lengths, permanent intermediate diaphragms shall be provided to stabilize the beams during construction.

To simplify the bill of materials, the longitudinal and transverse reinforcing bars in concrete diaphragms and transverse edge beams, except the #6 threaded bars, may be epoxy coated.

406-11.02 Intermediate Diaphragms

Intermediate diaphragms shall be provided for an I-beam or bulb-tee beam superstructure as follows.

1. For a span greater than 80 ft but less than or equal to 120 ft, provide diaphragms at the midspan.
2. For a span greater than 120 ft, provide diaphragms at the span third points.

A spread-box-beam superstructure having an inside radius of curvature of less than 800 ft shall have intermediate diaphragms between the individual boxes. The required spacing will depend upon the radius of curvature and the proportions of the webs and flanges. The diaphragms shall be placed on the radial lines. Other box-beam superstructures do not require intermediate diaphragms.

406-11.03 Structural-Steel and Reinforced-Concrete Interior Diaphragms

Structural-steel interior diaphragms shall be specified if interior diaphragms are required. This use of structural steel instead of concrete does not affect the bridge design. Structural-steel interior diaphragms shall be shown on the plans. The quantities in pounds shall be shown in the superstructure bill of materials and on the Bridge Summary sheet.

If it is determined that cast-in-place concrete interior diaphragms shall be used, the Director of Bridges shall be provided with a written justification for the concrete diaphragms. Once the Director concurs in the justification, such diaphragms shall be shown on the plans. The required quantities of concrete and reinforcing steel shall be incorporated into those for the bridge deck.

A note shall also be placed on the plans that states the following:

Concrete in the intermediate diaphragms shall attain a compressive strength of 3 ksi before the deck concrete is poured.

406-11.04 End Diaphragms

End diaphragms or edge beams are mandatory, though not on an adjacent precast-concrete box-beam superstructure. Integral end bents function as full-depth diaphragms. An end diaphragm serves the purposes as follows:

1. as a perimeter beam for the deck;
2. supports the deck-joint device; and
3. transfers lateral loads to the end bent.

For typical details of an end diaphragm, or transverse edge beam, see Section 404-3.03.

For typical details of integral end bents, see Section 409-2.01.

406-11.05 Interior Pier or Bent Diaphragms

End diaphragms are mandatory at each interior pier or bent, except for an adjacent precast concrete-box-beam superstructure. They serve the purposes as follows:

1. transfer lateral loads to the piers or bents, and
2. for beams made continuous for live load, strengthen the cast-in-place closure placement by providing lateral restraint.

The minimum diaphragm width for bulb-tee beams shall be 36 in., for I-beams 30 in., or for spread box beams 24 in. The clear distance between beam ends shall be 6 in. unless otherwise

approved. This dimension shall always be determined parallel to the longitudinal centerline of the beam.

See [Section 406-16.0](#) for typical details of cast-in-place concrete pier and bent diaphragms. The information illustrated in the figures therein is as follows:

1. diaphragm widths;
2. diaphragm reinforcement;
3. cap-keyway details;
4. clear distance between adjacent beam ends;
5. bearing-pad location details;
6. cap-sizing details; and
7. beam threaded-bar-hole/insert location details.

The figures in [Section 406-16.0](#) also show bearing layouts for a skewed structure with I-beams, bulb-tee beams, or box beams. For the same skew angle, the bearing pads are oriented differently in these figures. The ideal orientation of the pads, between the direction of the beams and the normal drawn to the bearing line, is a function of the skew, the length-to-width ratio, the component rigidities, and the position of loads. The structural significance of the orientation is small, therefore geometric requirements shall govern.

406-12.0 ADDITIONAL DESIGN FEATURES

406-12.01 General

Design requirements are provided for beams and girders, segmental construction, arches and slab superstructures in *LRFD* 5.14.1 through 5.14.4.

406-12.02 Prestressed-Concrete-Member Sections

406-12.02(01) General

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 shall be used.

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 shall 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

See Figures 406-13A through 406-13D for details and section properties. I-beam type IV shall not be used unless widening of an existing bridge is required. The 54-in.-depth beam shall be used for a new structure where this member depth and span length is required.

406-12.02(03) Indiana Bulb-Tee Beam

See Figures 406-14A through 406-14F, and 406-14M through 406-14R for details and section properties. For a long-span bridge, bulb-tee beams with a top-flange width of 60 in. shall be considered for improved stability during handling and transporting. Draped strands may be considered for use in a bulb-tee beam, but shall only be considered if tensile stresses in the top of the beam near its end are exceeded if using straight strands. The maximum allowable compressive strength, tensile strength, extent of strand debonding, and number of top strands shall be considered in evaluating the need for draped strands. If draped strands are used, the maximum allowable hold-down force per strand shall be 3.8 kip, with a maximum total hold-down force of 38 kip. 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](#).

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

406-12.02(04) Indiana Composite or Non-Composite Box Beam

See Figures 406-15A through 406-15L for details and section properties of composite members. See Figures 406-15M through 406-15R for details and section properties of non-composite members. It is not acceptable to use non-composite box beams for a permanent State highway bridge. The use of non-composite box beams is limited to a non-Federal-aid local public agency bridge, or a temporary bridge. The desirable limit for the end skew is 30 deg. An end skew of

over 30 deg shall be avoided unless measures have been considered for potential warping or cracking of the beam at its ends and congested reinforcement in the acute angle corner of the beam.

For a spread-box-beam structure, diaphragms of 8-in. thickness shall be placed within the box section for increased stability and torsion resistance during delivery and erection of the beams. The maximum spacing of the diaphragms is 25 ft.

For an adjacent-box-beams structure, interior diaphragms shall be provided to accommodate the transverse tension rods or tendons. Effective means for transferring shear between the box beams shall be provided (see [Section 406-12.06](#)). Because the longitudinal joints between adjacent box beams have shown a tendency to leak, use of adjacent box beams shall be limited to where maintaining a thin construction depth is critical, where construction time is critical, or where substantial life-cycle cost savings can be demonstrated.

Each void in a box beam shall be equipped with a vertical drainage pipe to prevent accumulation of water and ice therein. The inside diameter of the pipe shall be approximately 5/8 in. It shall be located at the lowest point of the void in the finished structure.

If the cost of a superstructure using precast-concrete AASHTO I-beams or bulb-tees is close to the cost of precast concrete spread box beams, the I-beam or bulb-tee superstructure is preferred unless other factors such as a thin structure depth are critical.

406-12.03 Strand Configuration and Mild-Steel Reinforcement

406-12.03(01) General

Mild reinforcing steel shall 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 shall 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

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 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 shall 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* 5.12.3.
3. Minimum concrete cover to stirrups and confinement reinforcement shall 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 shall be at least 6 in. from the outside edge of the flange.

406-12.03(03) Mild-Steel Reinforcement

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 shall be #4 stirrup bars where possible. To fully develop the bar for shear, the ends of the stirrup bar shall include a standard 90-deg stirrup hook. The maximum spacing of the vertical stirrups shall be in accordance with *LRFD* 5.8.2.7. The maximum longitudinal spacing of reinforcement for interface shear transfer shall be in accordance with *LRFD* 5.8.4.1.

A minimum of three horizontal U-shaped #4 bars shall 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* 5.10.10.1 requires that vertical mild reinforcement shall 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 mild reinforcing steel shall be provided to resist not less than 4% of the prestress force at transfer. The end vertical

bars shall be as close to the ends of the beam as possible. The stress in the reinforcing steel shall not exceed 20 ksi.

Confinement reinforcement in accordance with *LRFD* 5.10.10.2 shall 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 shall 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 Stage Loading for Pretensioned Construction

406-12.04(01) Strands Tensioned in the Stressing Bed

It is the fabricator's responsibility to consider seating losses, relaxation of the strands, and temperature changes in the strands prior to placement of the concrete during the fabrication of the beam and to make adjustments to the initial strand tension to ascertain that the tension prior to release satisfies the design requirements.

406-12.04(02) Strands Released and Force Transferred to the Concrete

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 shall 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 shall be assumed to be zero at the end of the beam or debonding point, and shall 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
4. draping some of the strands to reduce the strand eccentricity at the end of the beam.

406-12.04(03) Camber Growth and Prestress Losses

This condition occurs several weeks to several months after strand release. If a cast-in-place composite deck is placed, field adjustments to the haunch-fillet thickness are needed to provide the proper vertical grade on the top of deck and to keep the deck thickness uniform. Reliable estimates of deflection and camber are needed to prevent excessive fillet thickness or to avoid significant encroachment of the top of beam into the bottom of the concrete deck. Stresses at this stage are not critical.

Unless other more-accurate methods of determining camber are utilized (see *PCI Bridge Design Manual*, Section 8.7), the beam camber at the time of placement of the composite concrete deck shall be assumed to be the initial camber due to prestress minus the deflection due to the dead load of the beam times a multiplier of 1.75.

406-12.04(04) Maximum Service Load, Minimum-Prestress Stage

At this stage, all prestress losses have occurred and loads are at their maximum. The tensile stress in the bottom fibers of the beam at mid-span will likely control the design.

406-12.05 Continuity for Superimposed Loads

A multi-span bridge using composite beams shall 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 shall be assumed to be fully continuous with a constant moment of inertia in determining both the positive and negative moments due to superimposed loads.

The traditional method of making simply-supported beams continuous is to construct a closure joint between the adjacent beam ends over the pier, conveniently as part of the 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 shall 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 shall be designed in accordance with *LRFD* 5.14.1.4.8.

Continuity diaphragms shall be designed in accordance with *LRFD* 5.14.1.4.10 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 shall 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 shall be used to satisfy the negative-moment requirements.

406-12.06 Effect of Imposed Deformations

Potential positive moments at the piers shall 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.

For a span of over 150 ft or for concrete whose creep behavior is known to be poor, a time-dependent analysis shall be made to predict positive restraint moments at the piers. 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 shall 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 shall 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 shall 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 shall 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 shall not be debonded. The strands that are not used for the positive-moment connection shall be trimmed back to the beam end to permit ease of beam and concrete placement.

The prestressing-strand and concrete strengths shall be as shown in [Section 406-4.0](#). The tensile and compressive stress limits shall be as shown in *LRFD* 5.9.4. *LRFD* requires that only 80% of the live-load moment is to be applied in checking the tensile stress at service condition.

406-12.07 Transverse Connection of Precast Box Beams

The shear keys on adjacent, precast, prestressed box beams tend to crack and leak with a thin concrete deck placed composite with the beams. The following methods shall be considered toward minimizing cracking in the shear keys between the beams.

1. Use epoxy grout due to its high bond strength.
2. Use a full-depth shear key to stop the joint from performing like a hinge and prevent the joint from opening. In the past, the area below the key was open and free to rotate. With this area grouted, the movement of the joint will be reduced.
3. Apply compression across the joint by means of transverse tensioning rods. This will help prevent opening of the joint.

Figure 406-12A illustrates a method to minimize cracking in this type of structure.

The joints between the beam shear keys, and the recesses for the transverse tensioning rods on the exterior face of the beam, shall be grouted with an epoxy grout as shown in the figure.

After the joints between the beams are grouted, a preliminary tightening of the transverse tensioning rods shall be performed. Once this is completed, a final tensioning of the rods shall be performed to yield 20 ksi.

406-12.08 Segmental Construction

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 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 shall 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 Dimensioning Precast Beams

If a precast beam is to be placed on a longitudinal slope, its manufactured dimensions shall be modified to accommodate the geometric consequences of the grade. The casting bed is always horizontal. Consequently, the out-to-out beam length becomes L_{CL} , as follows:

$$L_{CL} = L / \cos \theta$$

where:

- θ = $\arctan (S/100)$ = angle of slope of the beam
- L = length of beam as it appears in plan view, ft
- S = slope of beam as shown in elevation view, percent

As shown in Figure 406-12B, the plans and the working drawings shall identify dimensions L , L_{CL} , a , and b . The seat surfaces are always horizontal and the end surfaces are always vertical once the beam is in place.

Maintaining vertical end surfaces of the in-place beams often has only a minimal effect on the constructability of this type of superstructure, and need be considered only where dimension b in Figure 406-12B exceeds $1\frac{1}{2}$ in.

If the slope of the beam between supports is more than 1.0%, a beveled recess will be required in the bottom of the beam at the supports. For an integral end bent, a steel sole plate cast into the beam recess will be required. The recess in the bottom flange of the beam shall have a minimum recess dimension of $\frac{1}{4}$ in. The minimum concrete cover over the prestressing strands at the opposite end of the recess shall be 1 in. as shown in Figure 406-12B. For a severe grade where use of the minimum $\frac{1}{4}$ -in. recess results in less than 1 in. of cover, either the beam seat shall be sloped, or the bottom strand clearance shall be increased in $\frac{1}{4}$ -in. increments until the 1-in. cover is achieved.

For a beam length in excess of 80 ft, the length of the prestressing strands prior to release shall be increased due to the elastic shortening, creep, and shrinkage anticipated to occur prior to casting the deck slab. Due to variables beyond the designer's control, the beam fabricator is responsible for making this change.

To avoid sharp corners which can be damaged during construction due to a skew of 15 deg or greater, a chamfer of at least 3 in. width shall be placed at each acute corner of a prestressed box beam.

406-12.10 Other Design Features

406-12.10(01) Skew

Although normal flexural effects due to live load tend to decrease as the skew angle increases, shear does not. There is a considerable redistribution of shear forces in the end zone due to the development of involuntary negative moments therein. For a skew angle of less than 30 deg, the skew may be ignored, and the bridge may be analyzed as a square structure whose span lengths are equal to the skewed span lengths.

LRFD 4.6.2.2.2e and 4.6.2.2.3c provide tabulated assistance to roughly estimate these live-load effects. The factors shown in the tables can be applied to either a simple span or a continuous-spans skewed bridge. The correction factors for shear apply only to support shears at the obtuse corner of an exterior beam. Shear in portions of the beam away from the end supports need not be corrected for skew effects.

To obtain a better assessment of skewed-structure behavior and to utilize potential benefits in reduced live-load moments, more sophisticated methods of analysis are required. The refined methods most often used to study skewed-structure behavior are the grillage analysis and the

finite element method. The finite element analysis requires the fewest simplifying assumptions in accounting for the greatest number of variables that govern the structural response of the bridge. However, input preparation time and derivation of overall forces for a composite beam can be tedious. Data preparation for the grillage method is simpler, and integration of stresses is not needed.

406-12.10(02) Shortening of Superstructure

For a long continuous structure, the shortening of the superstructure due to creep, shrinkage, temperature, and post-tensioning, if applicable, shall be considered in the design of the beam supports and the substructure.

406-13.0 AASHTO I-BEAMS

Figures 406-13A through 406-13D show details and section properties for these beams.

406-14.0 INDIANA BULB-TEE BEAMS

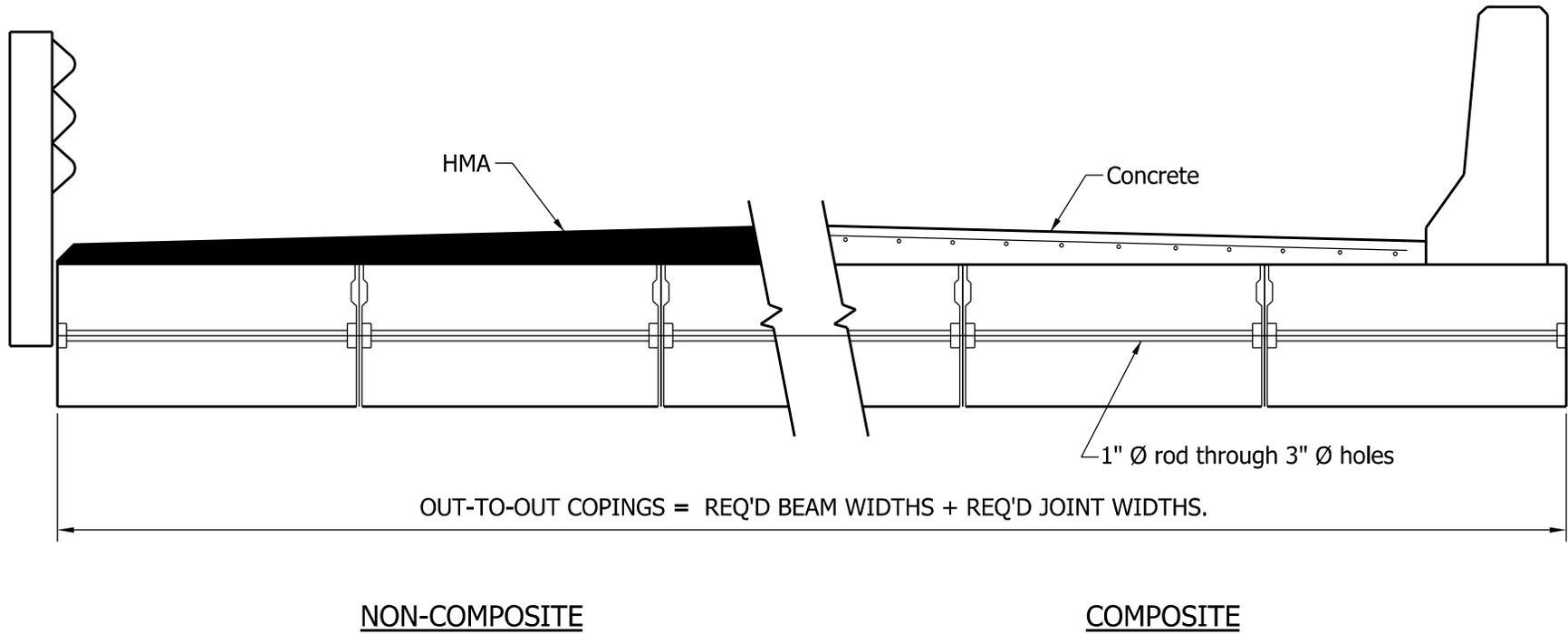
Figures 406-14A through 406-14Z show details and section properties for these beams.

406-15.0 INDIANA COMPOSITE AND NON-COMPOSITE BOX BEAMS

Figures 406-15A through 406-15R show details and section properties for these beams.

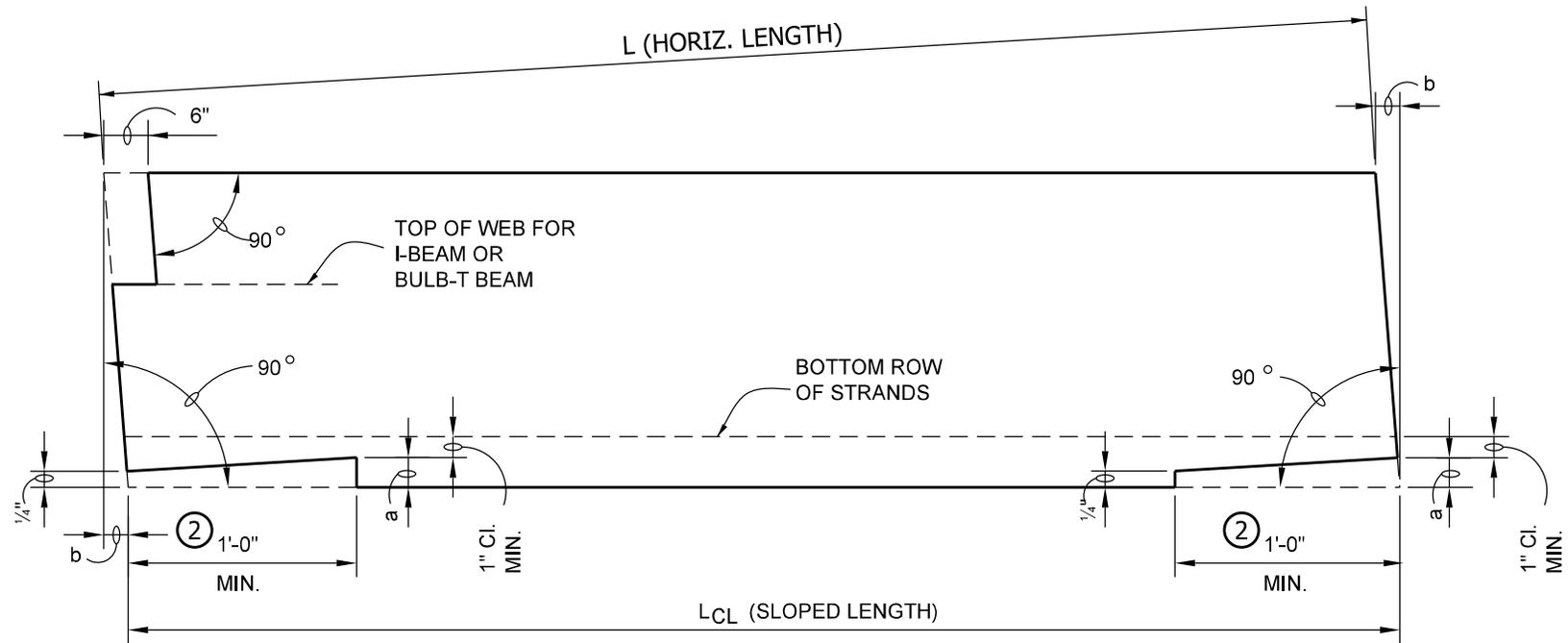
406-16.0 MISCELLANEOUS DETAILS

Figures 406-16A through 406-16X show details for diaphragms, closure pours, support cap sizing, and bearing pad layouts for I beams, bulb-tees, and box beams.



ADJACENT BOX BEAMS WITH TRANSVERSE TENSIONING RODS
(Section View)

Figure 406-12A

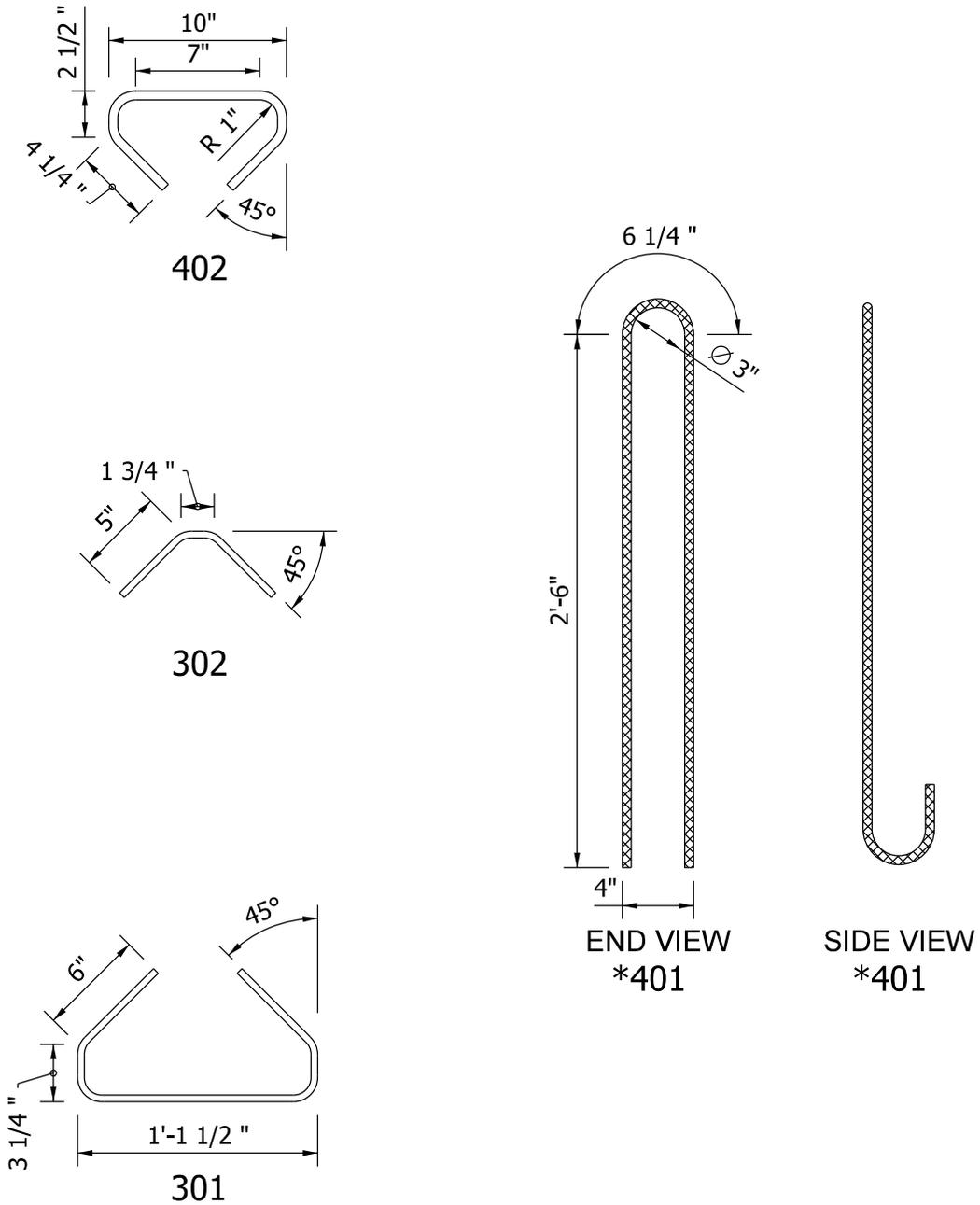
**NOTES:**

1. BEAM FABRICATOR IS RESPONSIBLE FOR ADJUSTING THE CASTING LENGTH TO ACCOMMODATE AN INCREASE IN BEAM LENGTH DUE TO DIMENSION *b*. IF DIMENSION *b* IS LESS THAN 1 1/2 in., THE END OF THE BEAM SHALL NOT BE ADJUSTED.
- ② THE LENGTH OF THE RECESS SHALL PROVIDE A BEAM OVERHANG OF AT LEAST 2 in. PAST THE FACE OF THE BEARING PAD FOR A BULB-T BEAM OR 1 in. FOR AN I-BEAM OR A BOX BEAMS.

DIMENSIONING PRESTRESSED-CONCRETE BEAM ON SLOPE

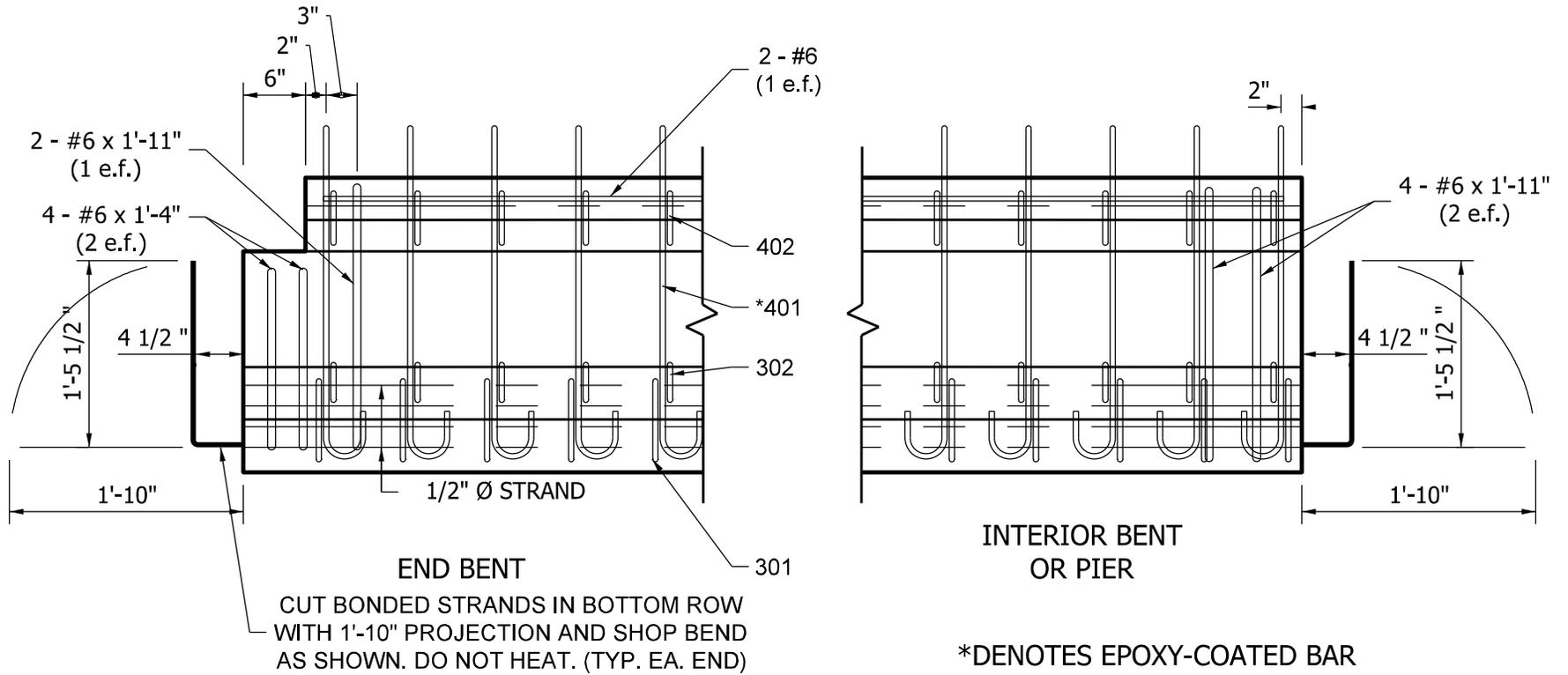
Figure 406-12B

☒ * DENOTES EPOXY-COATED BAR



I - BEAM TYPE I BAR BENDING DETAILS

Figure 406-13A
(page 2 of 3)

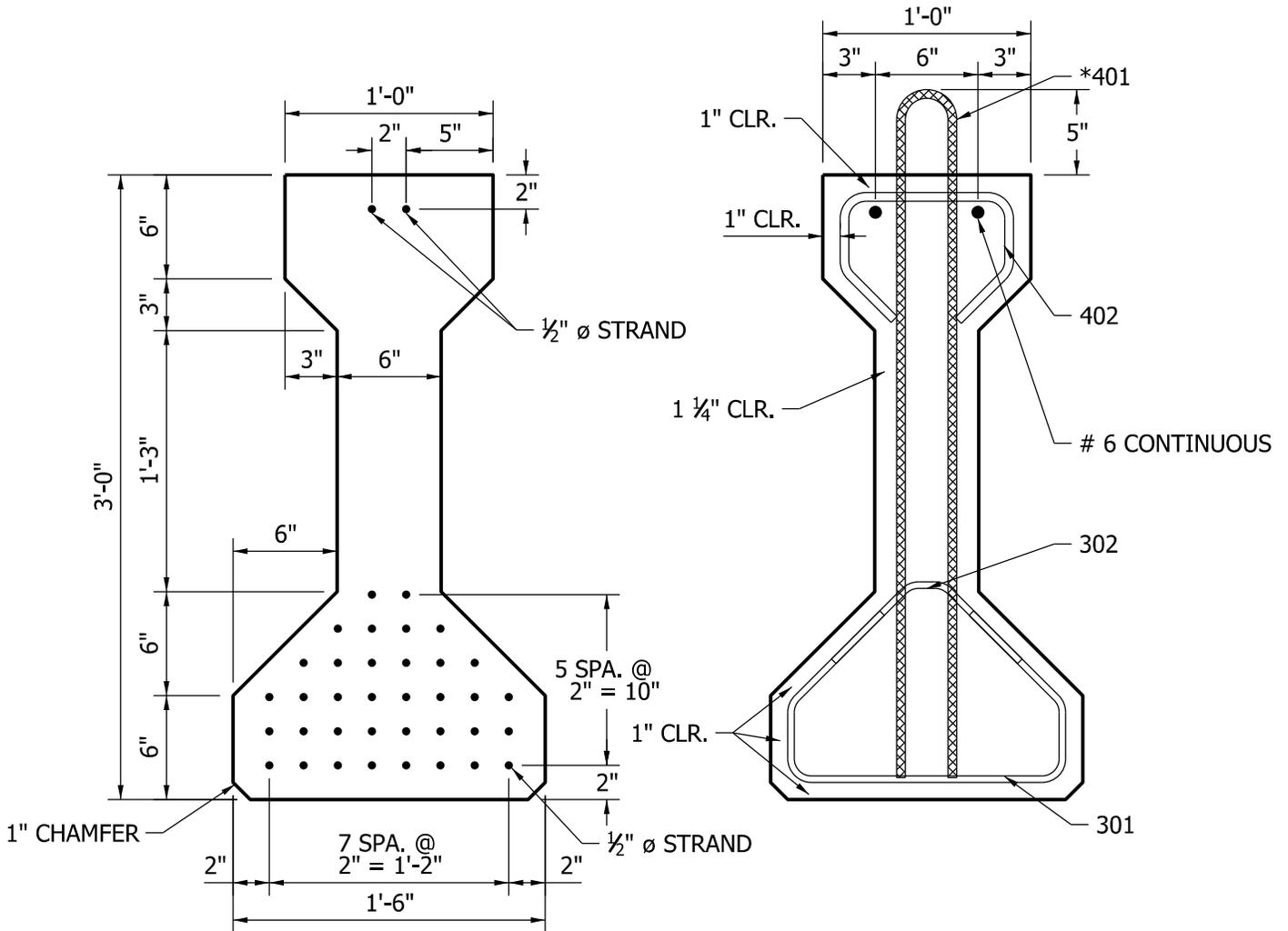


I - BEAM TYPE I ELEVATIONS SHOWING END REINFORCEMENT

Figure 406-13A
(page 3 of 3)

BEAM PROPERTIES	
A_B	= 369 in. ²
I_B	= 50,979 in. ⁴
S_{TB}	= 2,527 in. ³
S_{BB}	= 3,221 in. ³
Y_{TB}	= 20.2 in.
Y_{BB}	= 15.8 in.
Wt.	= 384 lb/lf

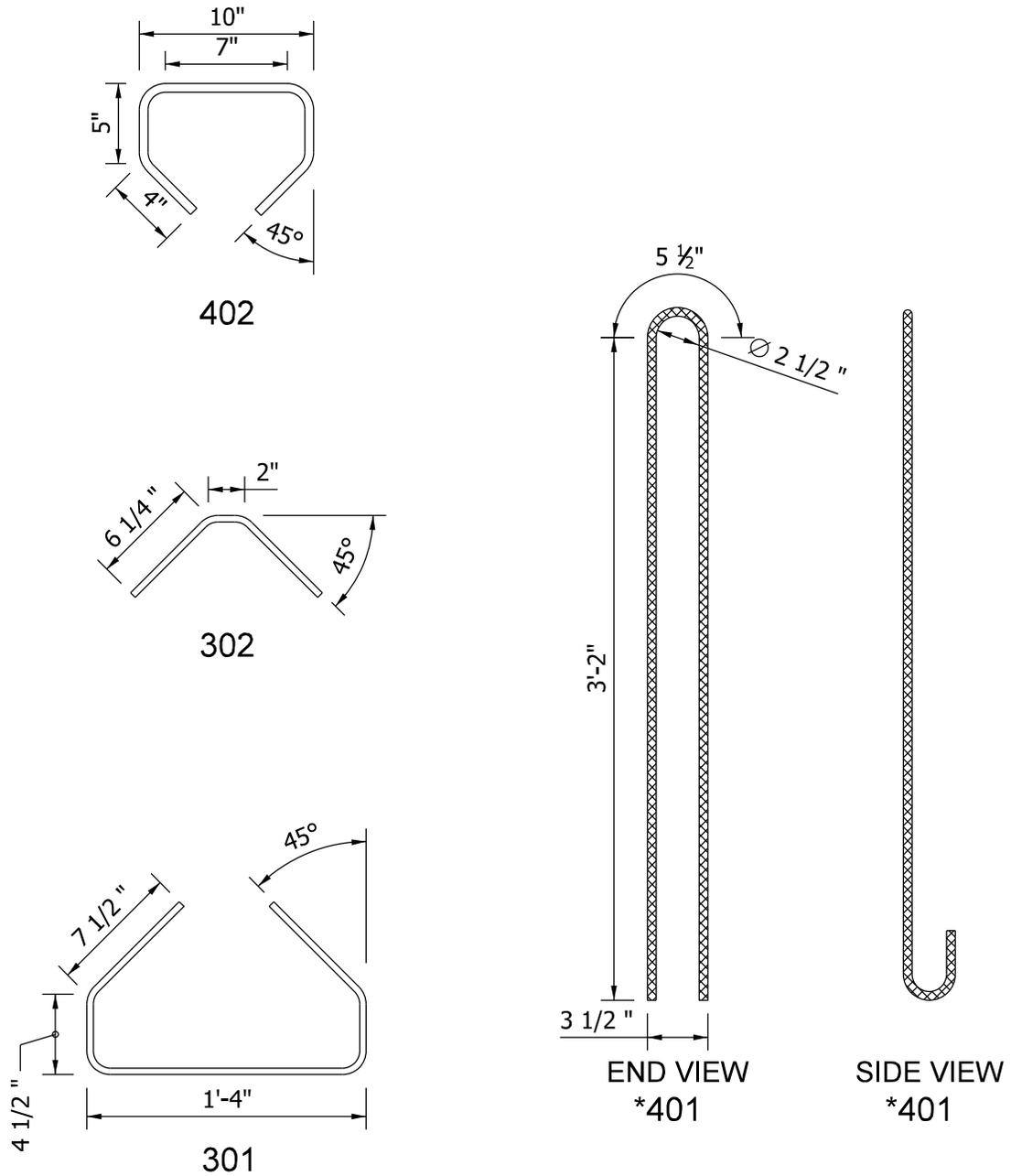
- NOTES:
1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.
 2.  *DENOTES EPOXY-COATED BAR



I - BEAM TYPE II

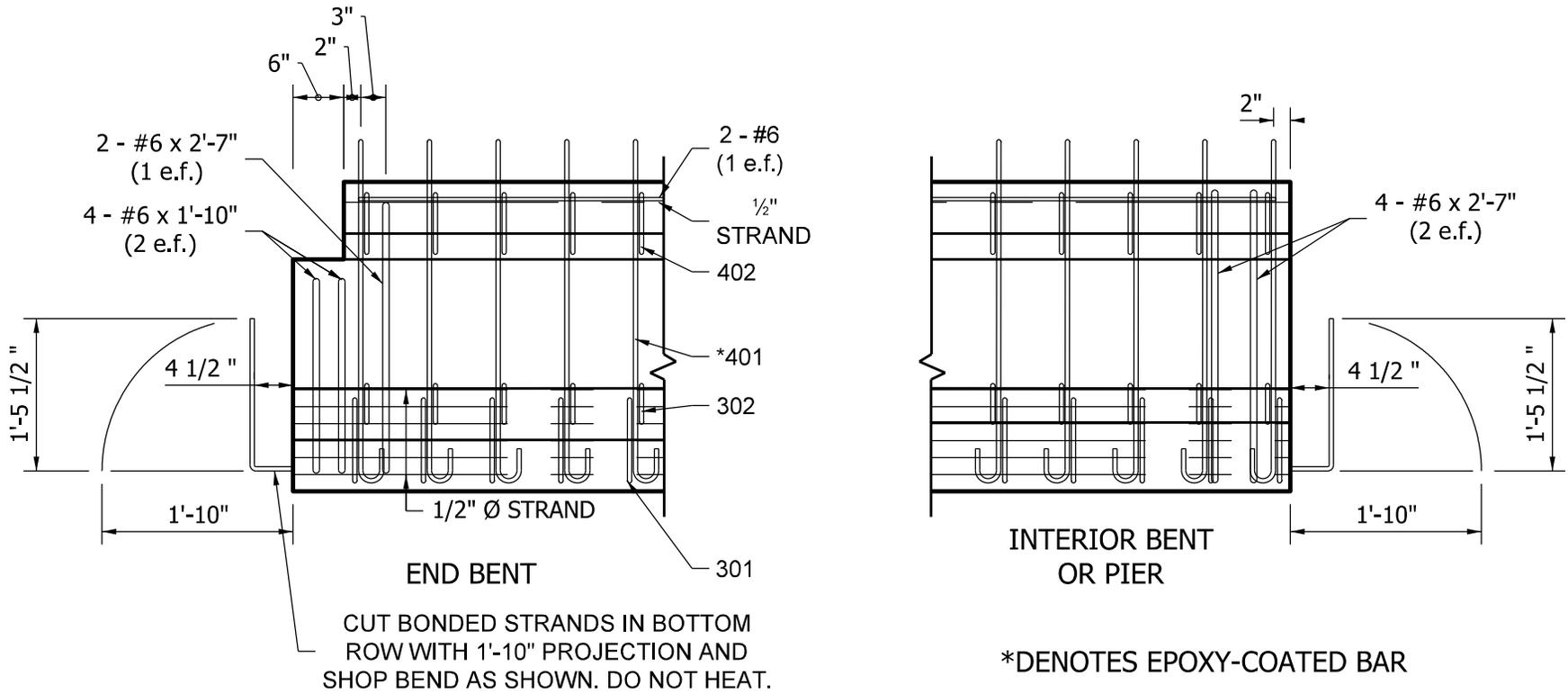
Figure 406-13B
(page 1 of 3)

☒ * DENOTES EPOXY-COATED BAR



I - BEAM TYPE II BAR BENDING DETAILS

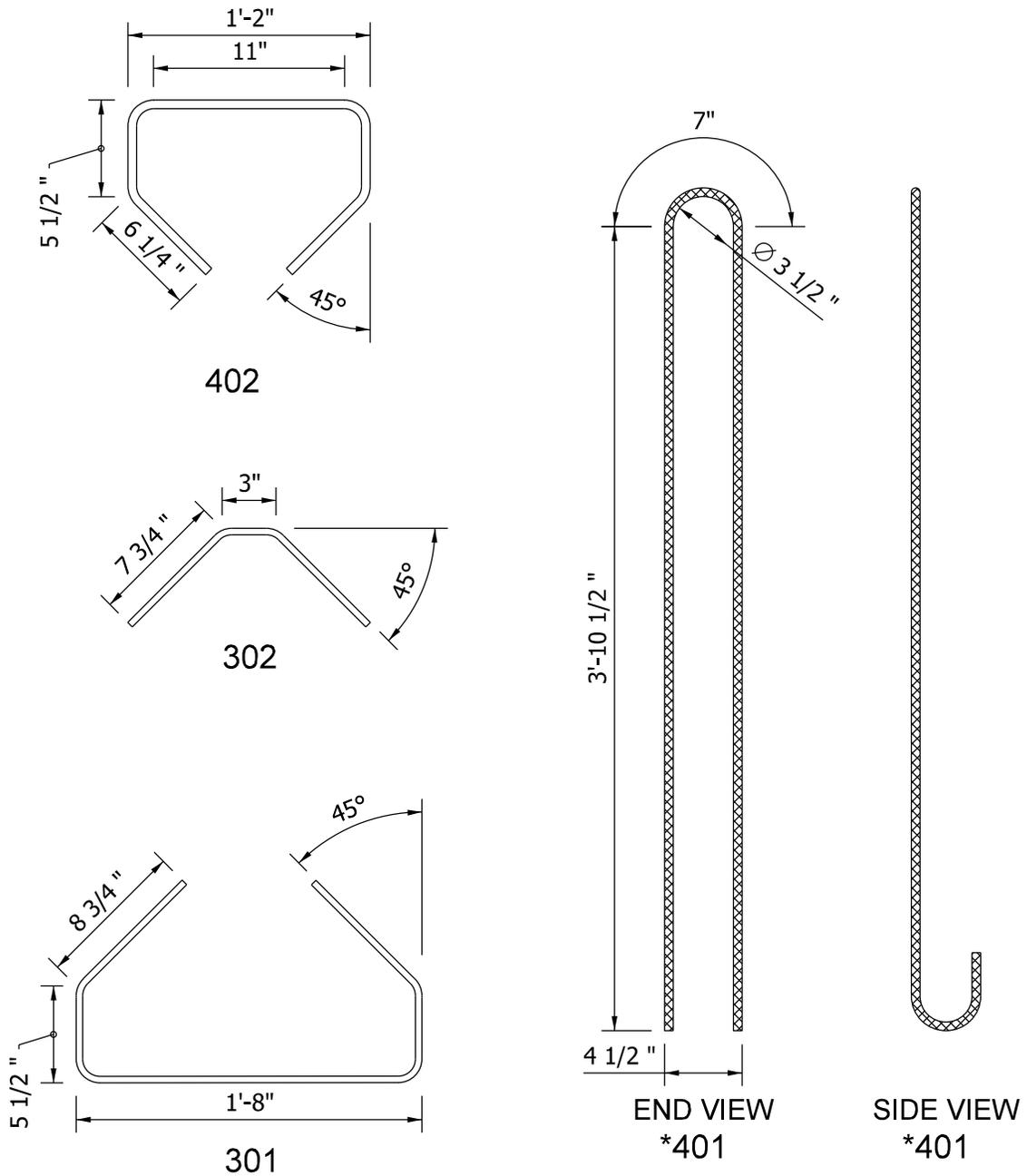
Figure 406-13B
(page 2 of 3)



I - BEAM TYPE II
 ELEVATIONS SHOWING END REINFORCEMENT

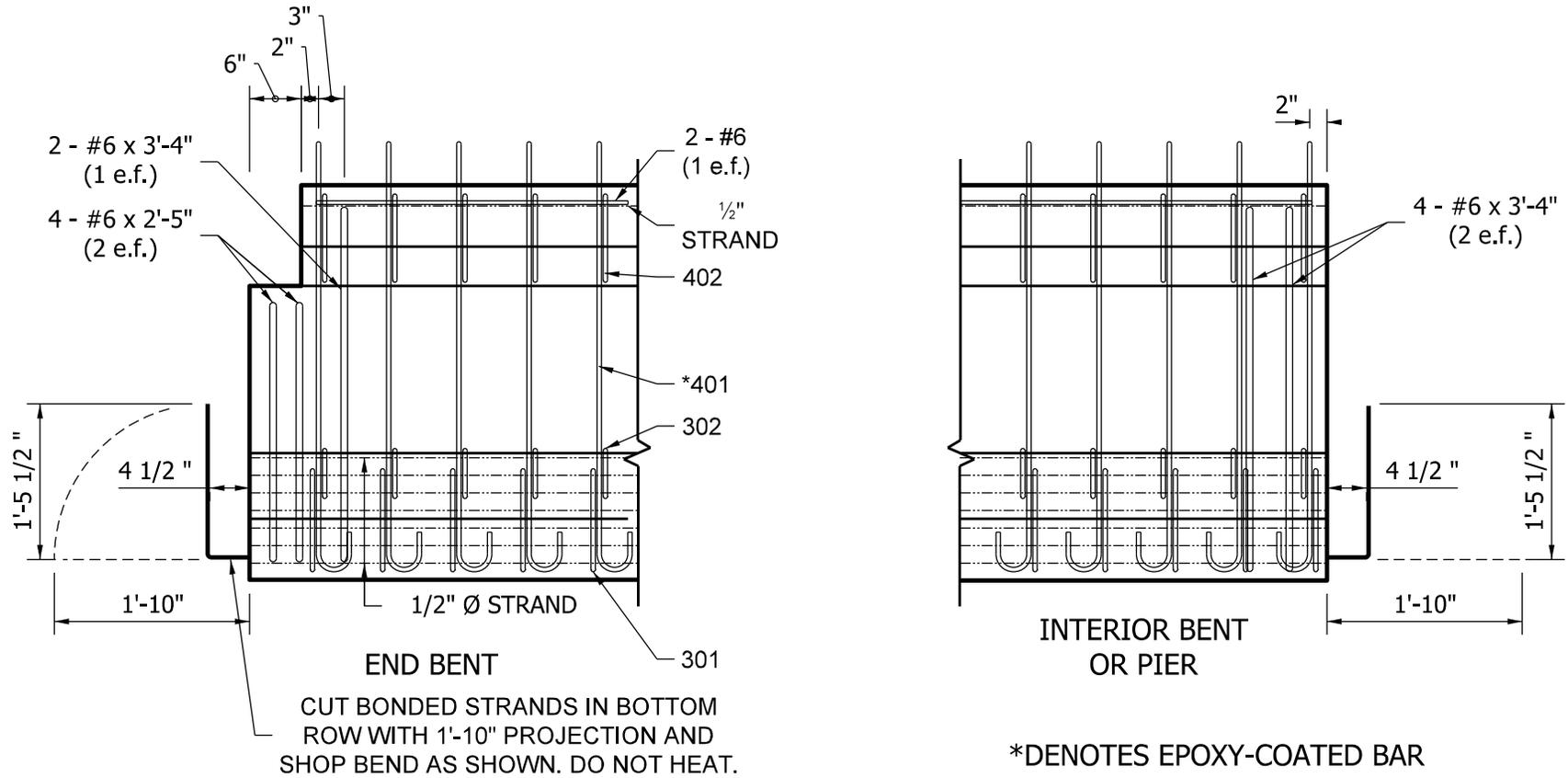
Figure 406-13B
 (page 3 of 3)

☒ * DENOTES EPOXY-COATED BAR



I - BEAM TYPE III BAR BENDING DETAILS

Figure 406-13C
(page 2 of 3)

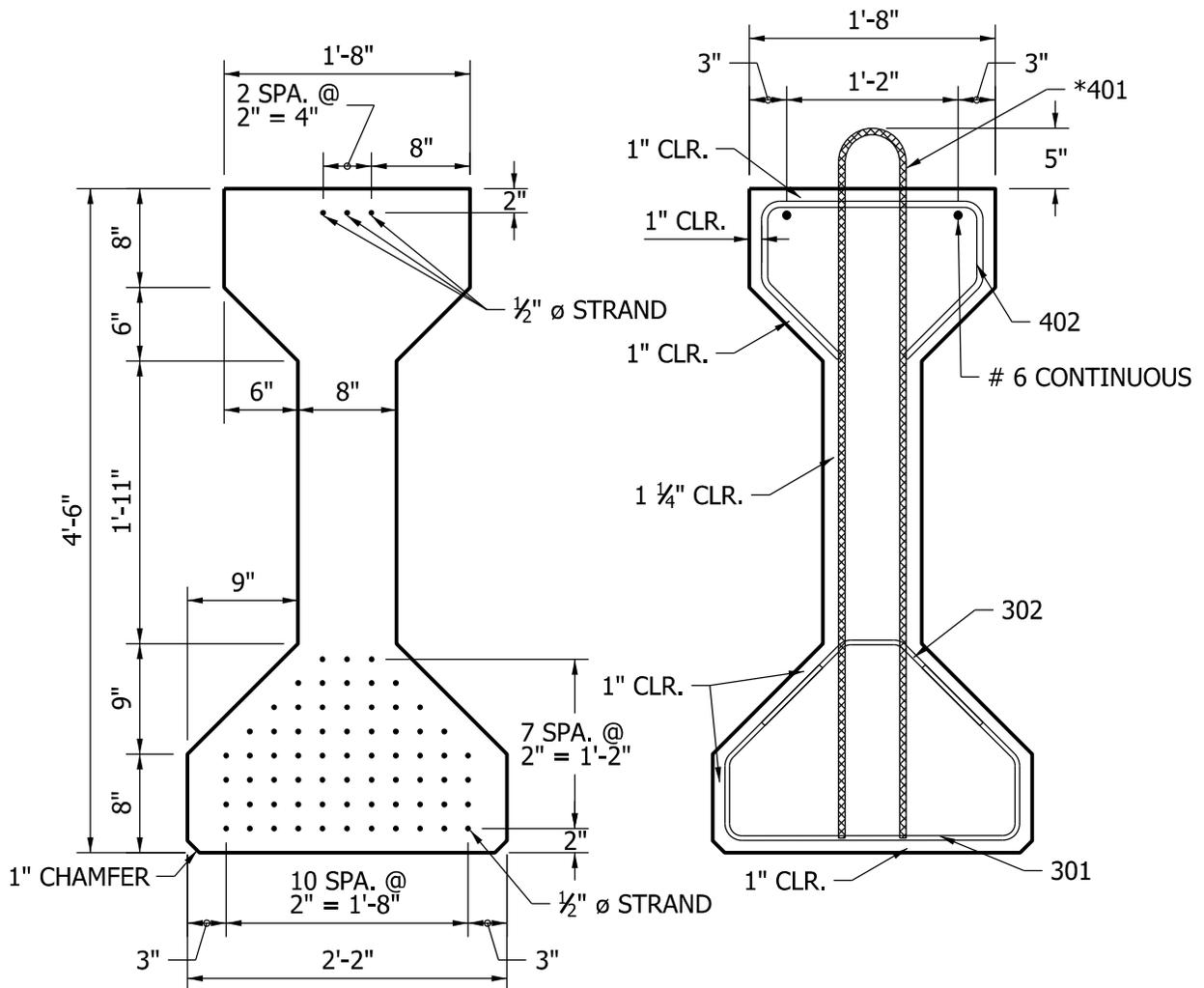


I - BEAM TYPE III
 ELEVATIONS SHOWING END REINFORCEMENT

Figure 406-13C
 (page 3 of 3)

BEAM PROPERTIES	
A_B	= 789 in. ²
I_B	= 260,741 in. ⁴
S_{TB}	= 8,909 in. ³
S_{BB}	= 10,542 in. ³
Y_{TB}	= 29.3 in.
Y_{BB}	= 24.7 in.
Wt.	= 822 lb/lf

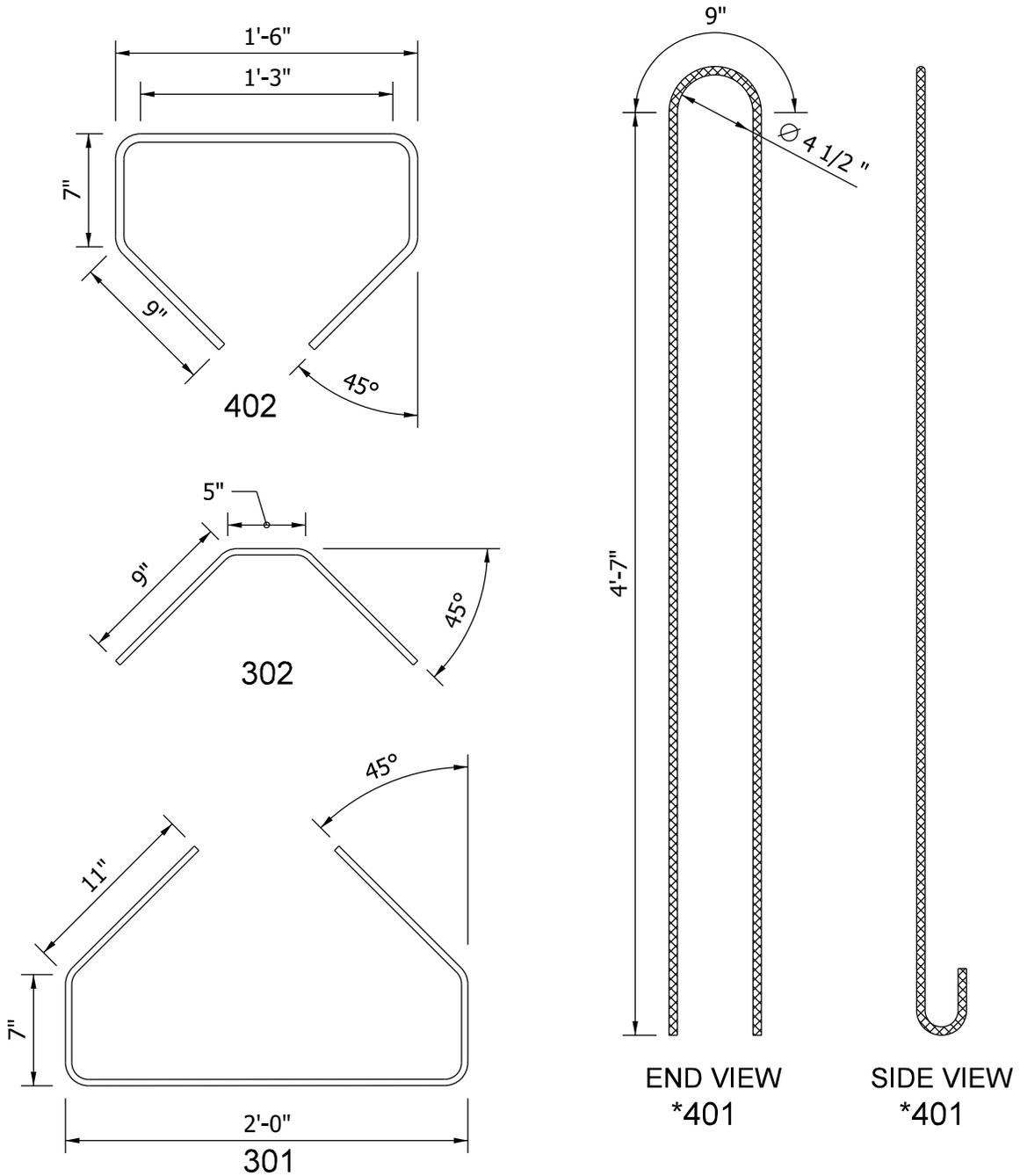
- NOTES:
1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.
 2.  *DENOTES EPOXY-COATED BAR



I - BEAM TYPE IV

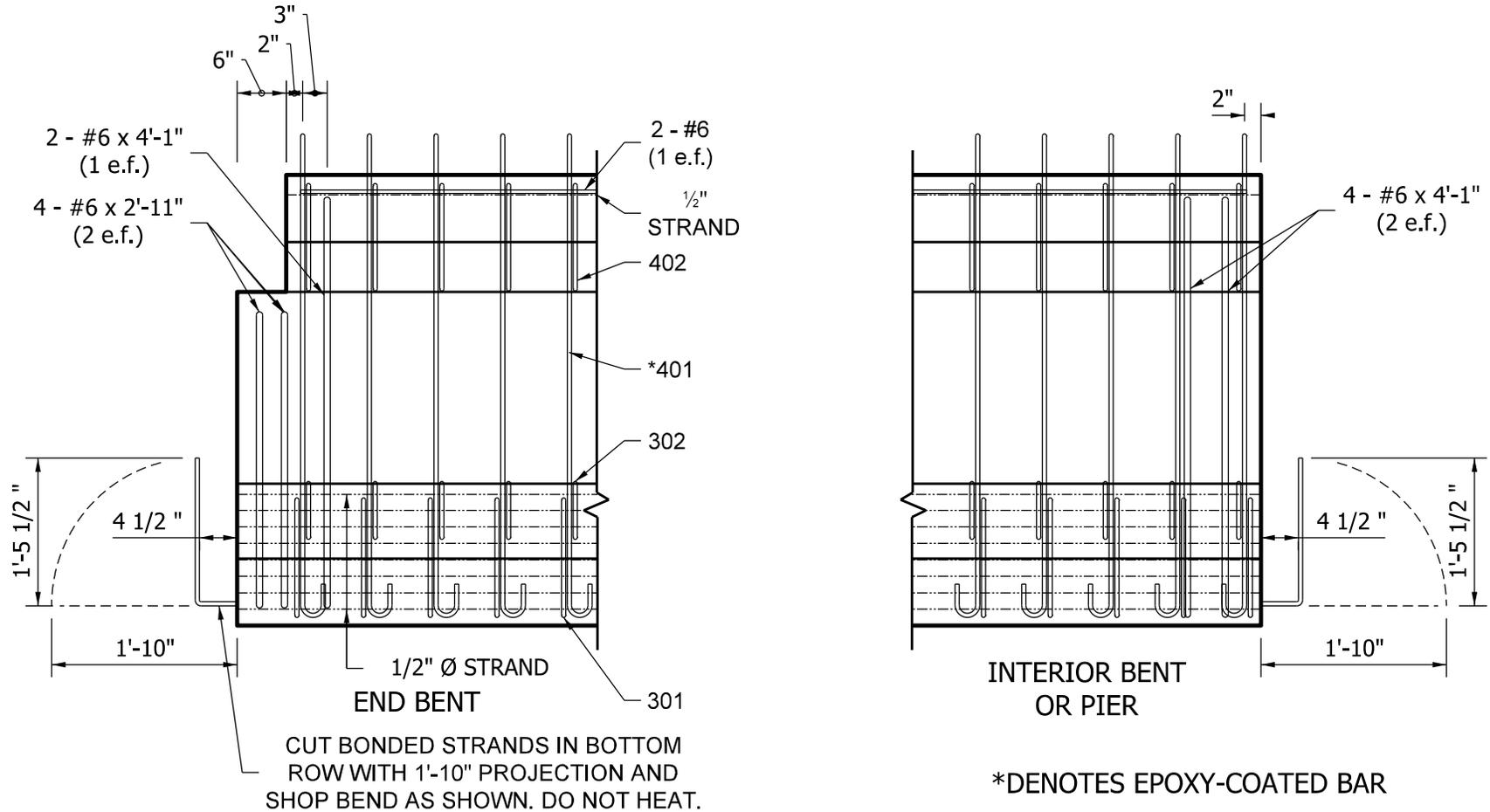
Figure 406-13D
(Page 1 of 3)

☒ * DENOTES EPOXY-COATED BAR



I - BEAM TYPE IV BAR BENDING DETAILS

Figure 406-13D
(Page 2 of 3)



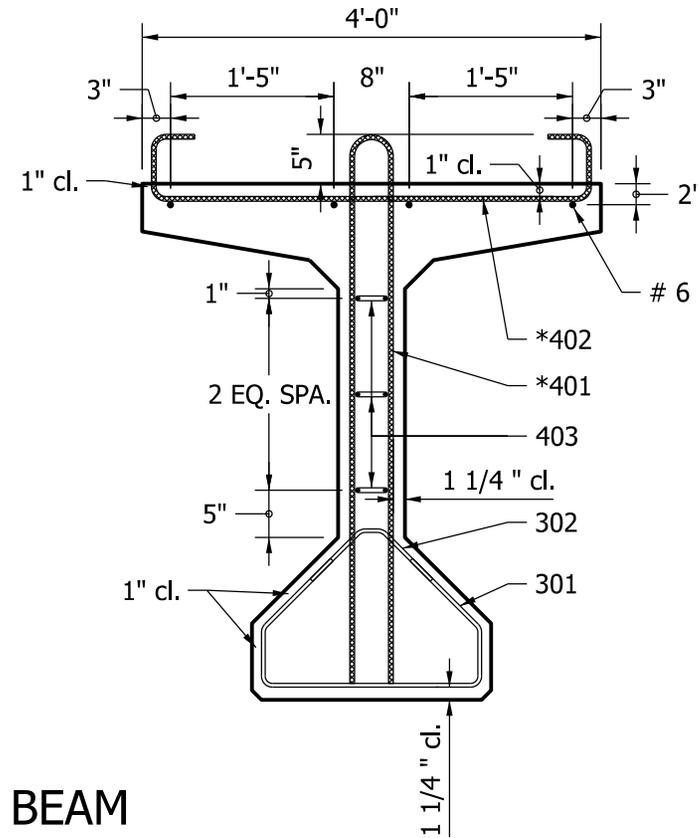
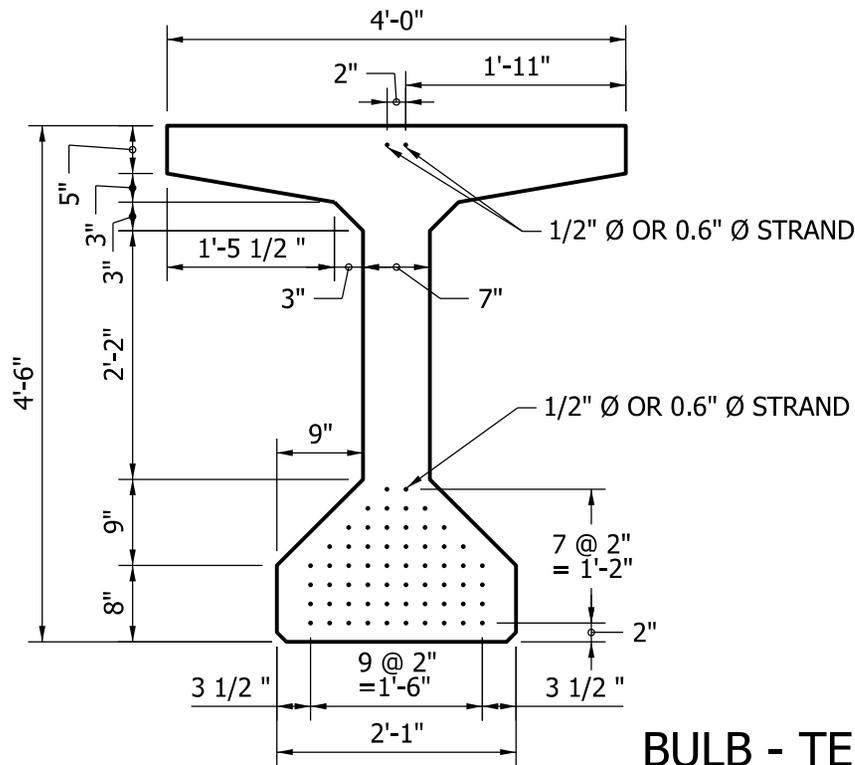
I - BEAM TYPE IV ELEVATIONS SHOWING END REINFORCEMENT

Figure 406-13D
(Page 3 of 3)

BEAM PROPERTIES	
A_B	= 883 in ²
I_B	= 340,892 in ²
S_{TB}	= 13,756 in ³
S_{BB}	= 11,667 in ³
Y_{TB}	= 24.8 in
Y_{BB}	= 29.2 in
Wt.	= 920 lb/lf

NOTES:

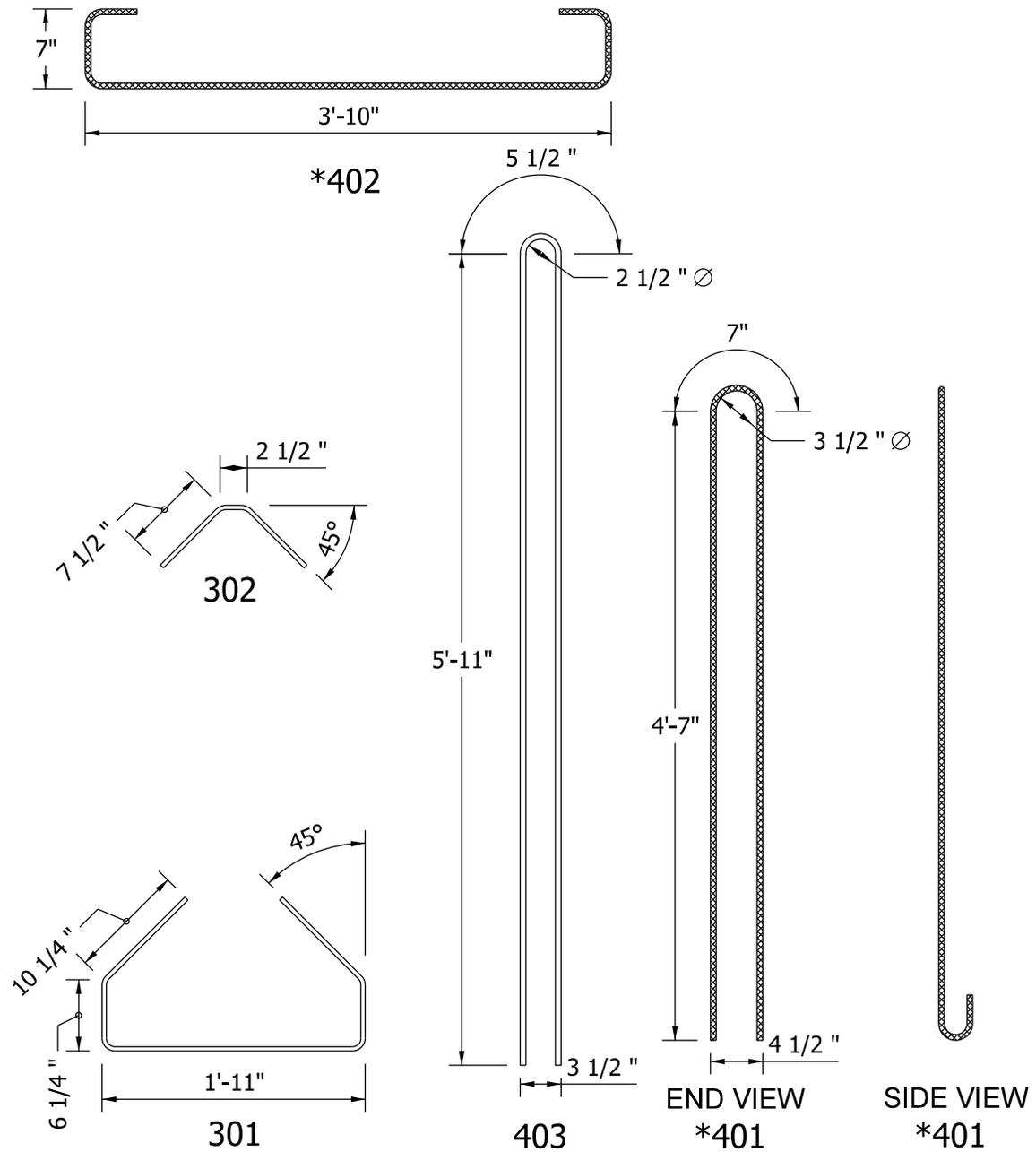
1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 54 x 48**

Figure 406-14A
(Page 1 of 2)

☒ * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 54 x 48
BAR BENDING DETAILS**

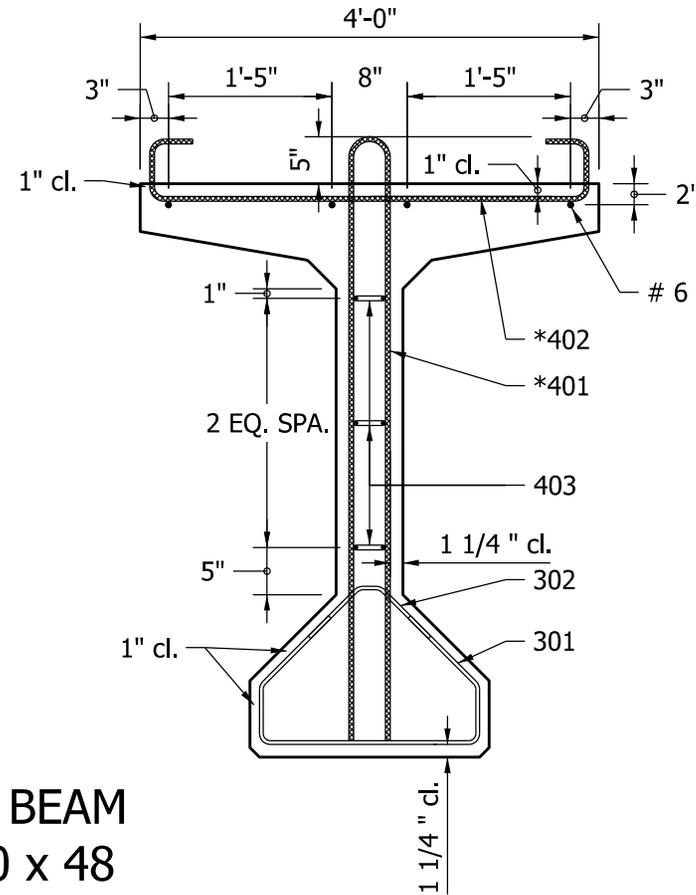
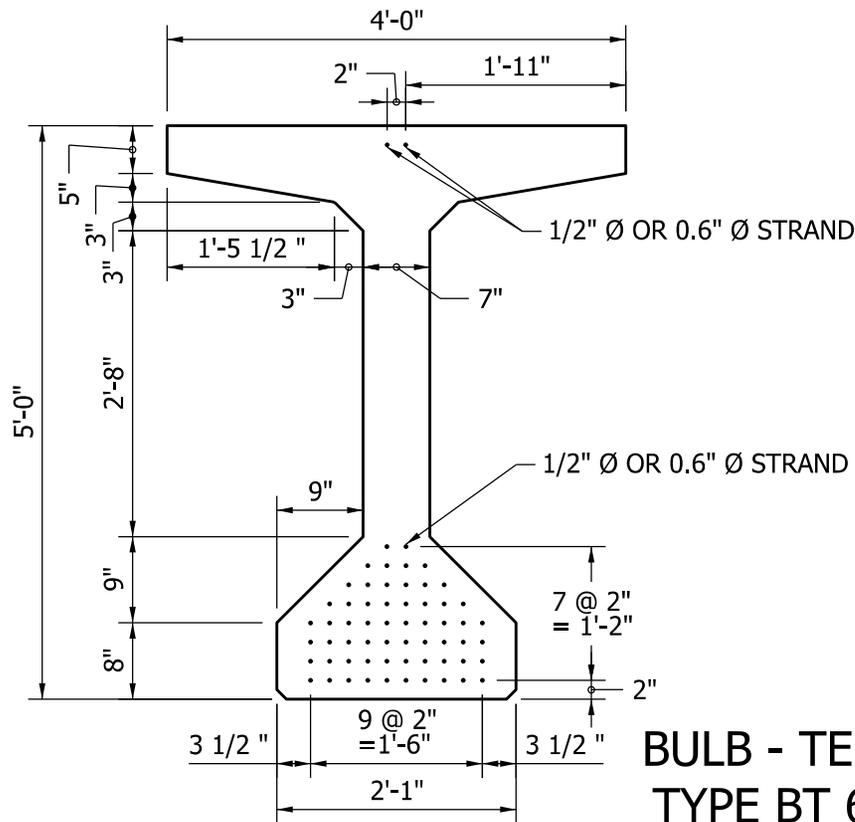
Figure 406-14A
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 932 in ²
I_B	= 449,526 in ²
S_{TB}	= 16,324 in ³
S_{BB}	= 13,847 in ³
Y_{TB}	= 27.5 in
Y_{BB}	= 32.5 in
Wt.	= 971 lb/lf

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

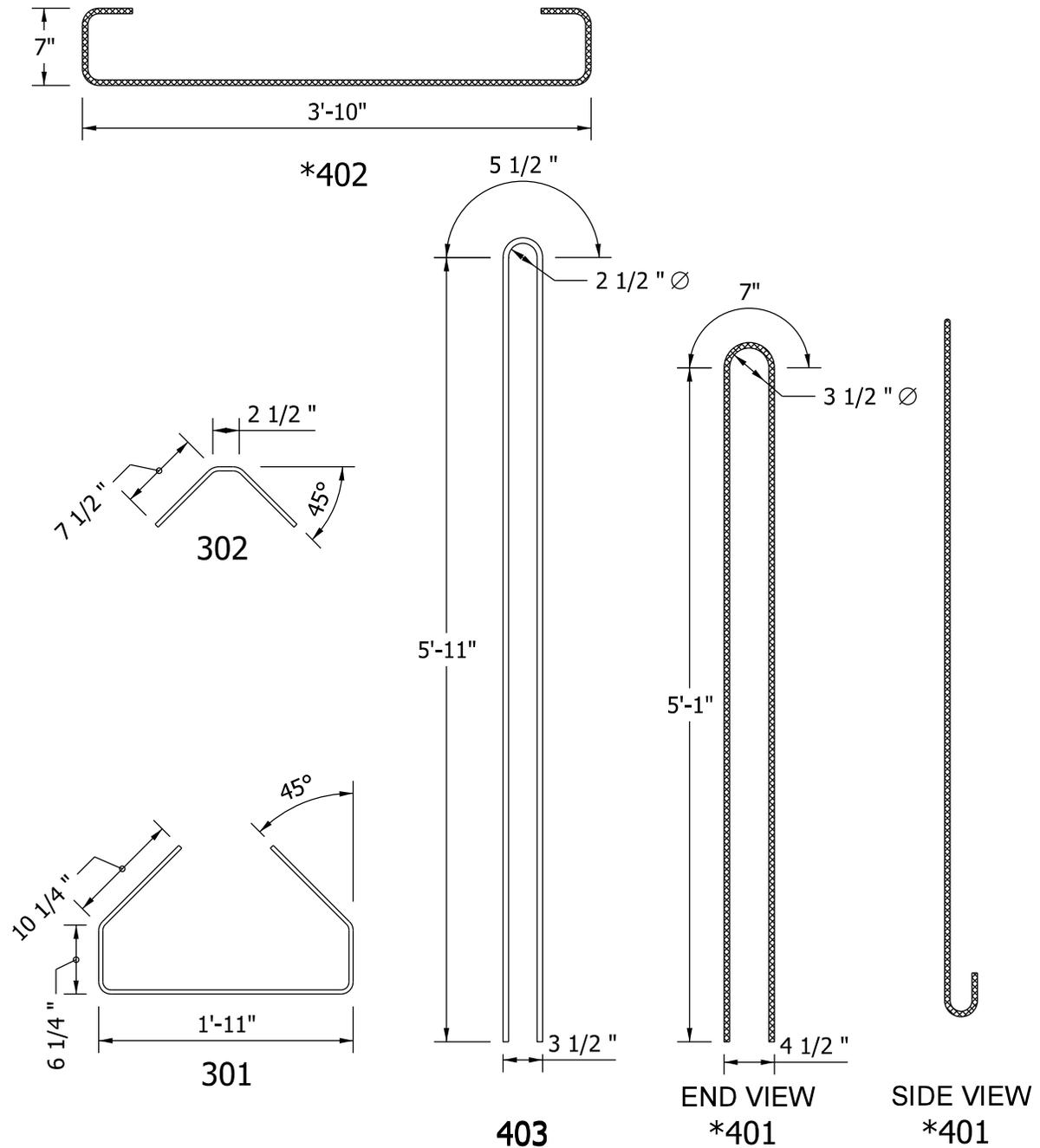
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 60 x 48**

Figure 406-14B
(Page 1 of 2)

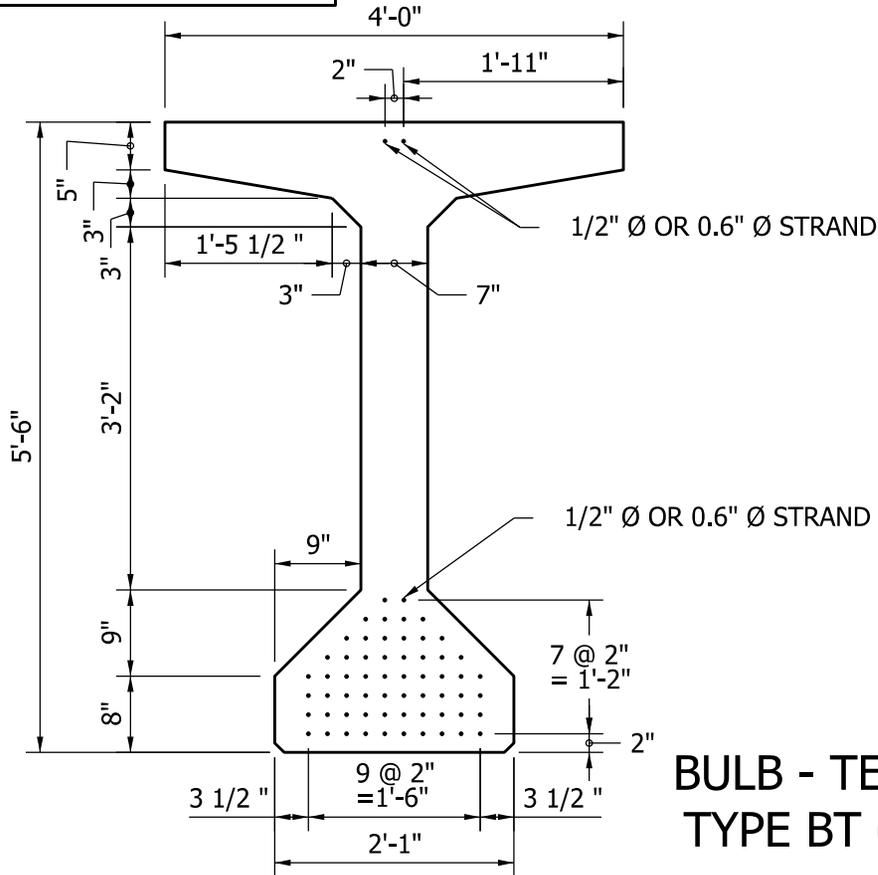
 * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 60 x 48
BAR BENDING DETAILS**

Figure 406-14B
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 974 in ²
I_B	= 572,338 in ⁴
S_{TB}	= 18,794 in ³
S_{BB}	= 16,101 in ³
Y_{TB}	= 30.5 in
Y_{BB}	= 35.5 in
Wt.	= 1015 lb/lf



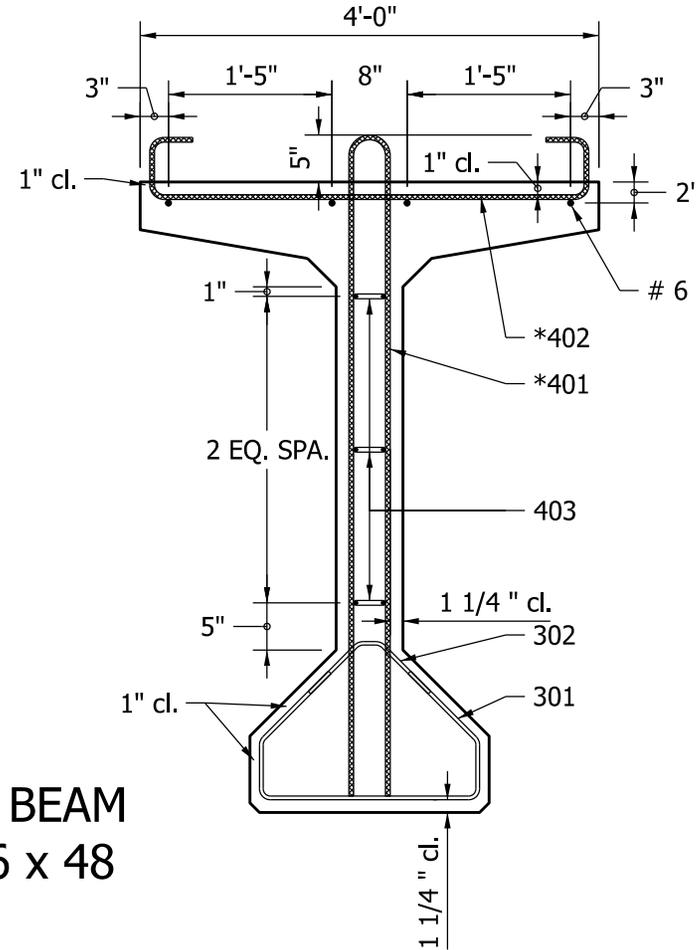
**BULB - TEE BEAM
TYPE BT 66 x 48**

Figure 406-14C
(Page 1 of 2)

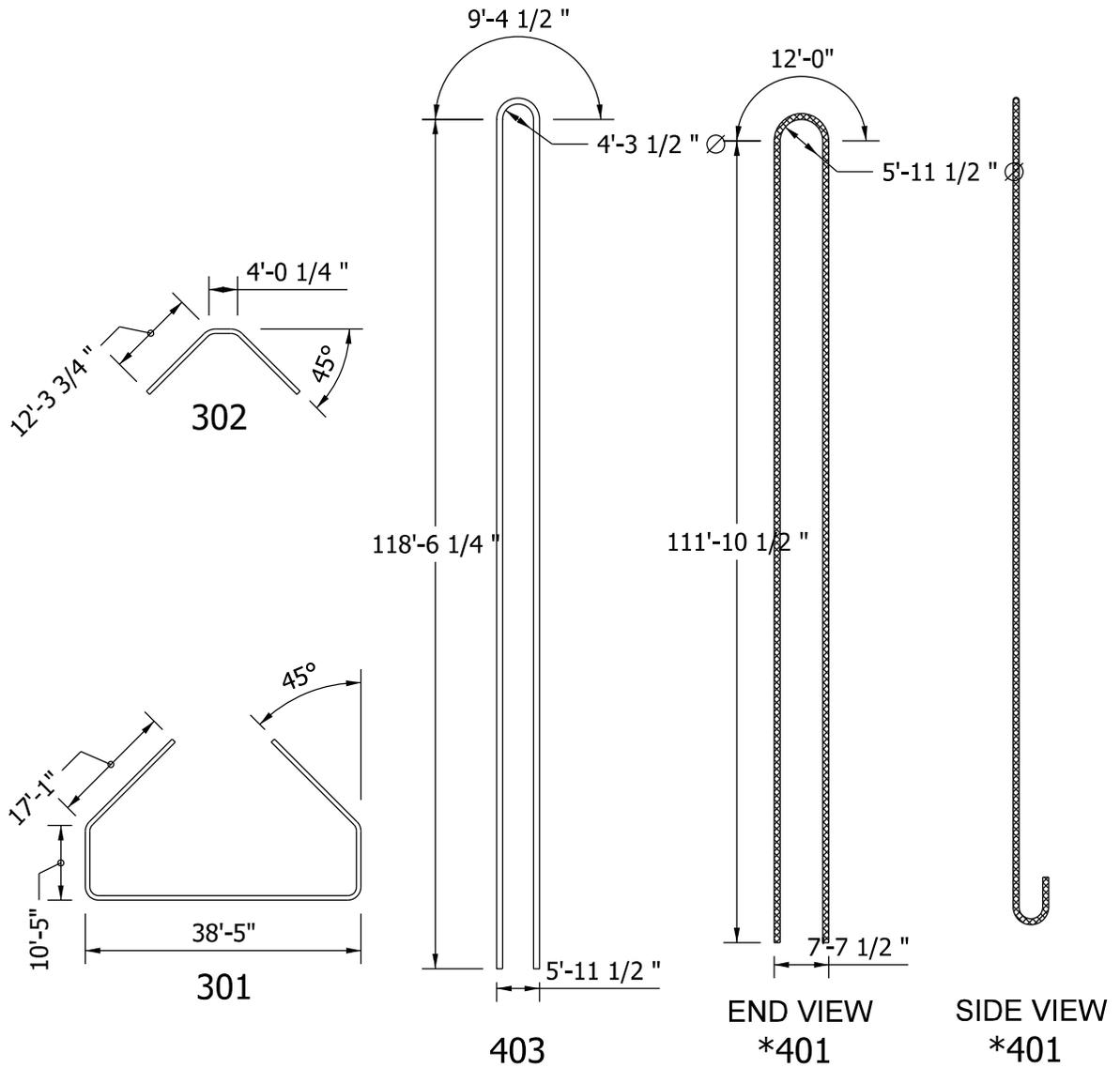
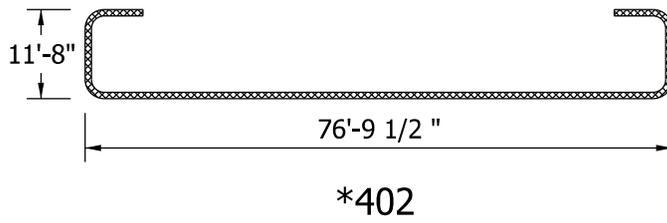
NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

2. *DENOTES EPOXY-COATED BARS



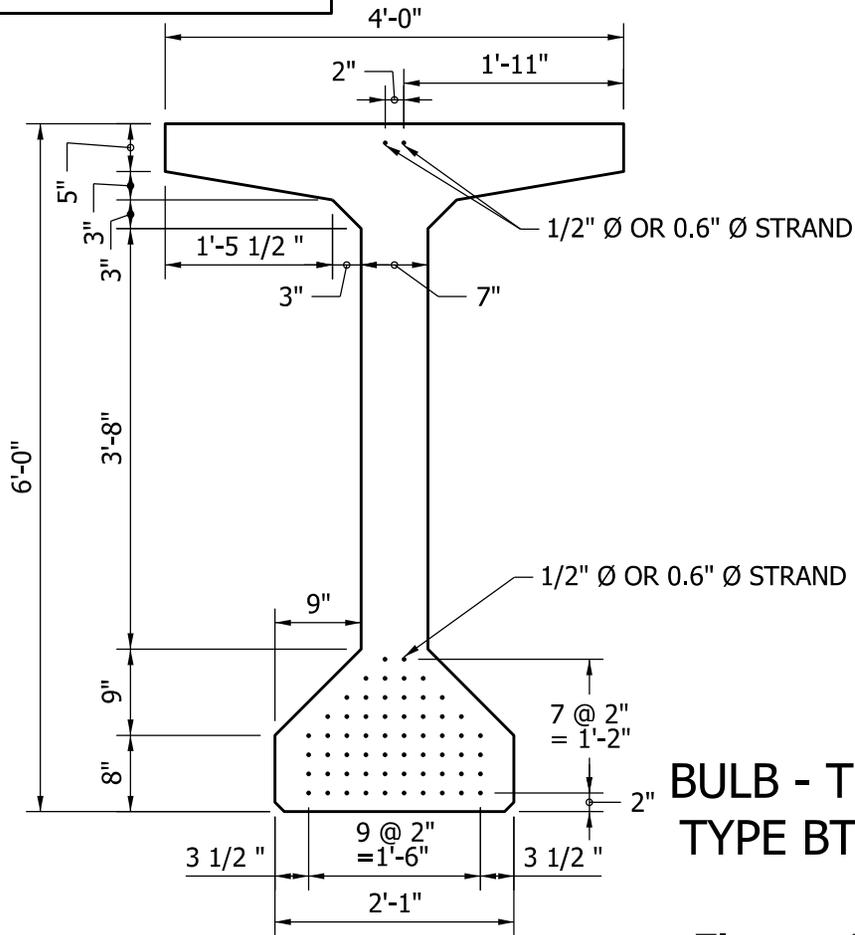
 * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 66 x 48
BAR BENDING DETAILS**

Figure 406-14C
(Page 2 of 2)

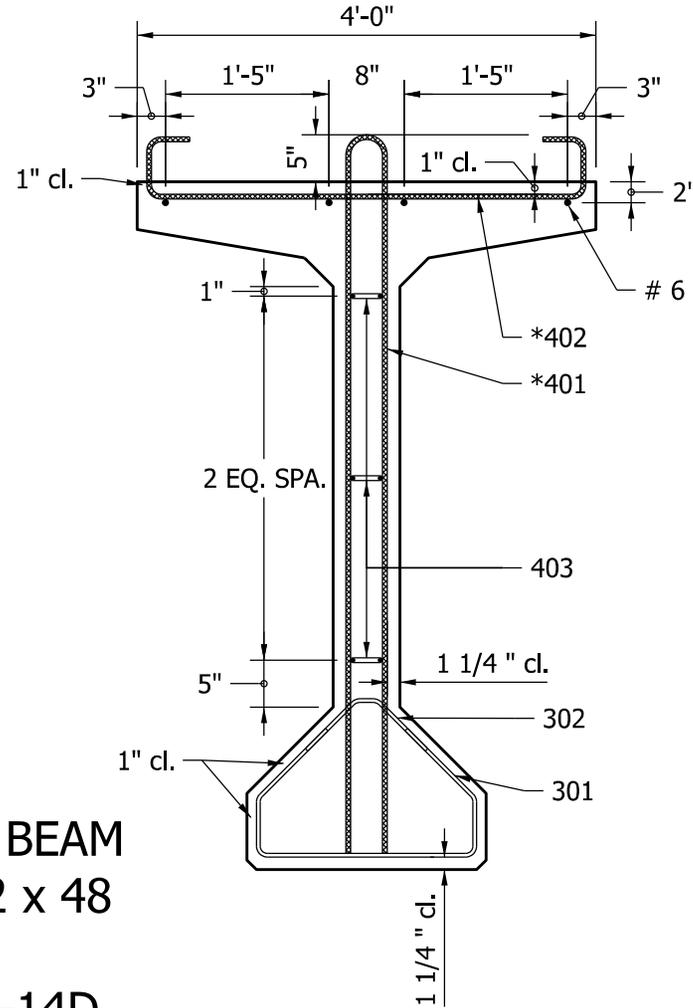
BEAM PROPERTIES	
A_B	$= 1016 \text{ in}^2$
I_B	$= 712,670 \text{ in}^2$
S_{TB}	$= 21,354 \text{ in}^3$
S_{BB}	$= 18,451 \text{ in}^3$
Y_{TB}	$= 33.4 \text{ in}$
Y_{BB}	$= 38.6 \text{ in}$
Wt.	$= 1058 \text{ lb/lf}$



NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

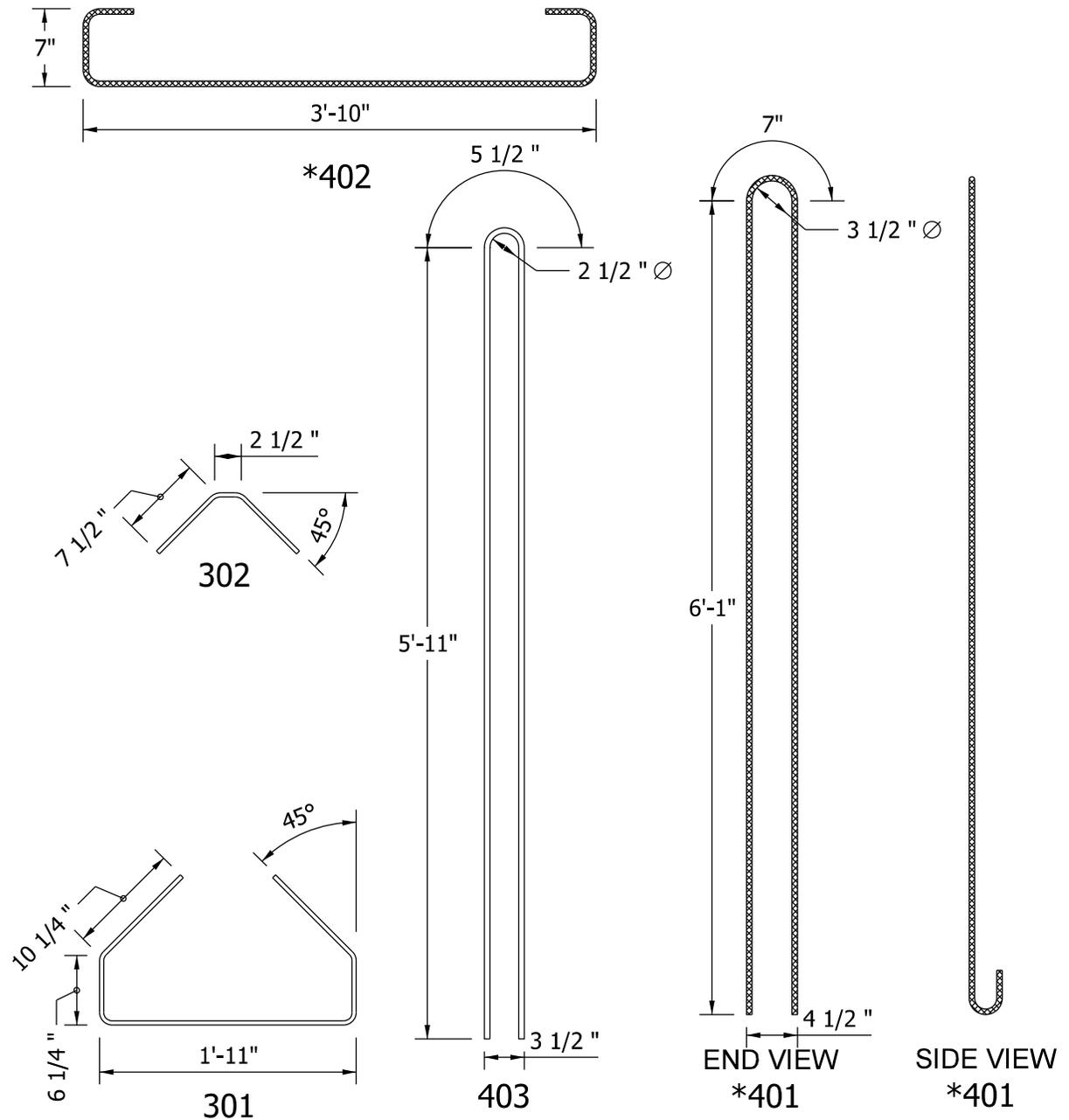
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 72 x 48**

Figure 406-14D
(Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 72 x 48
BAR BENDING DETAILS**

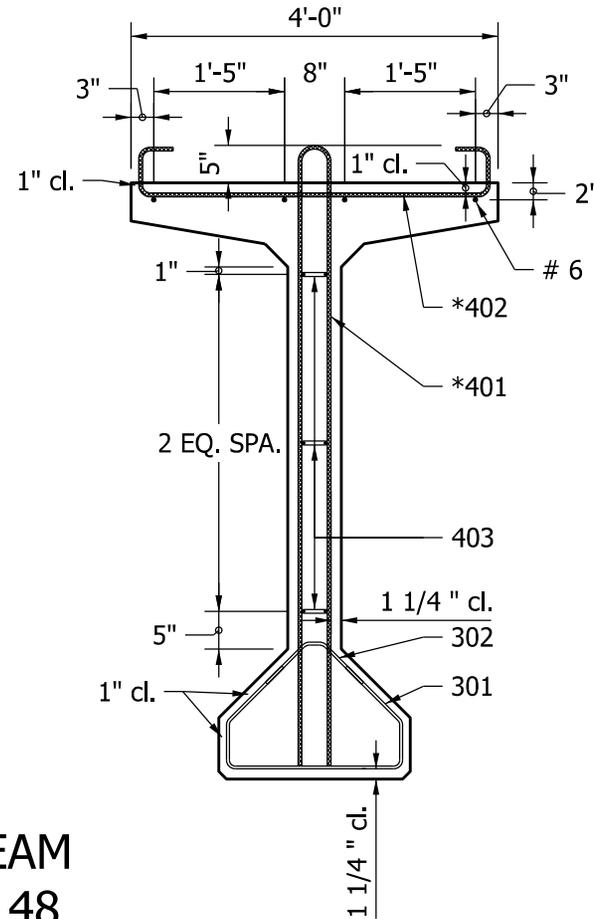
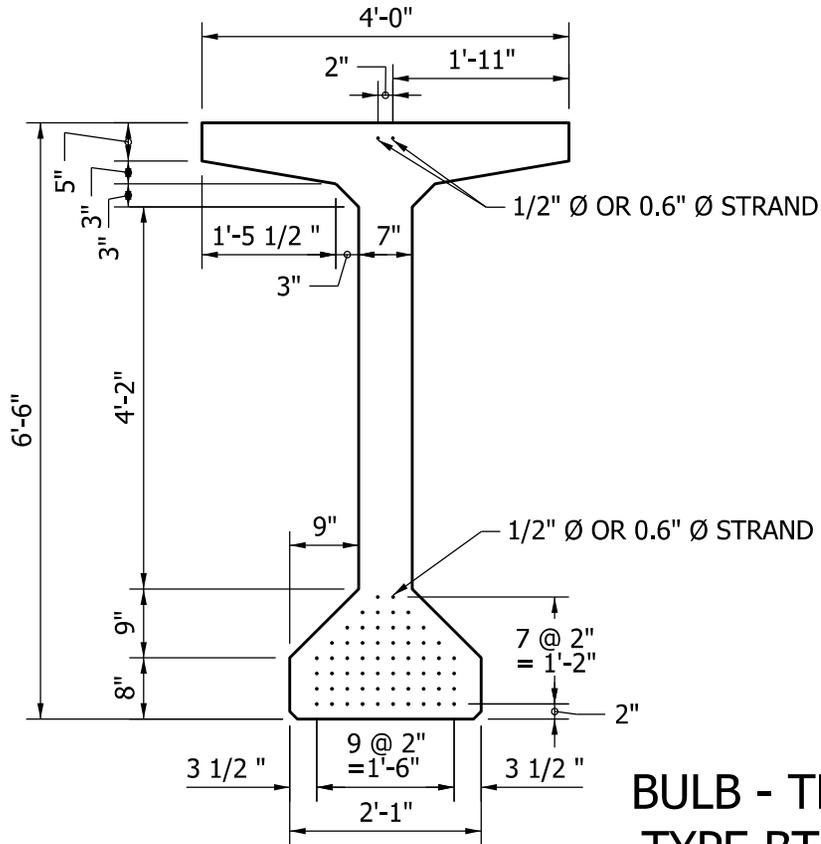
Figure 406-14D
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 1058 in ²
I_B	= 871,279 in ²
S_{TB}	= 24,000 in ³
S_{BB}	= 20,896 in ³
Y_{TB}	= 36.3 in
Y_{BB}	= 41.7 in
Wt.	= 1102 lb/ft

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

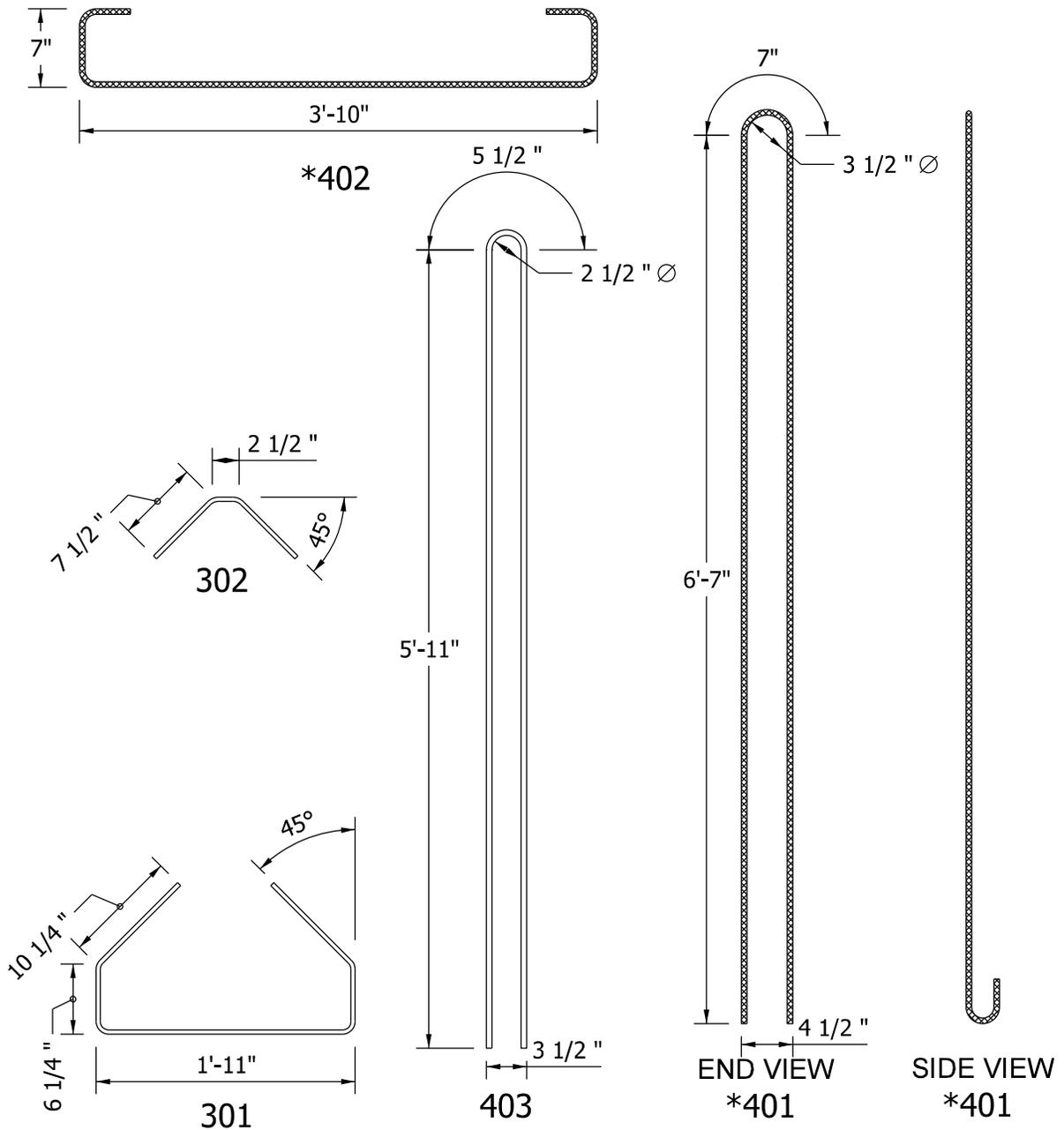
2.  *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 78 x 48**

Figure 406-14E
(Page 1 of 2)

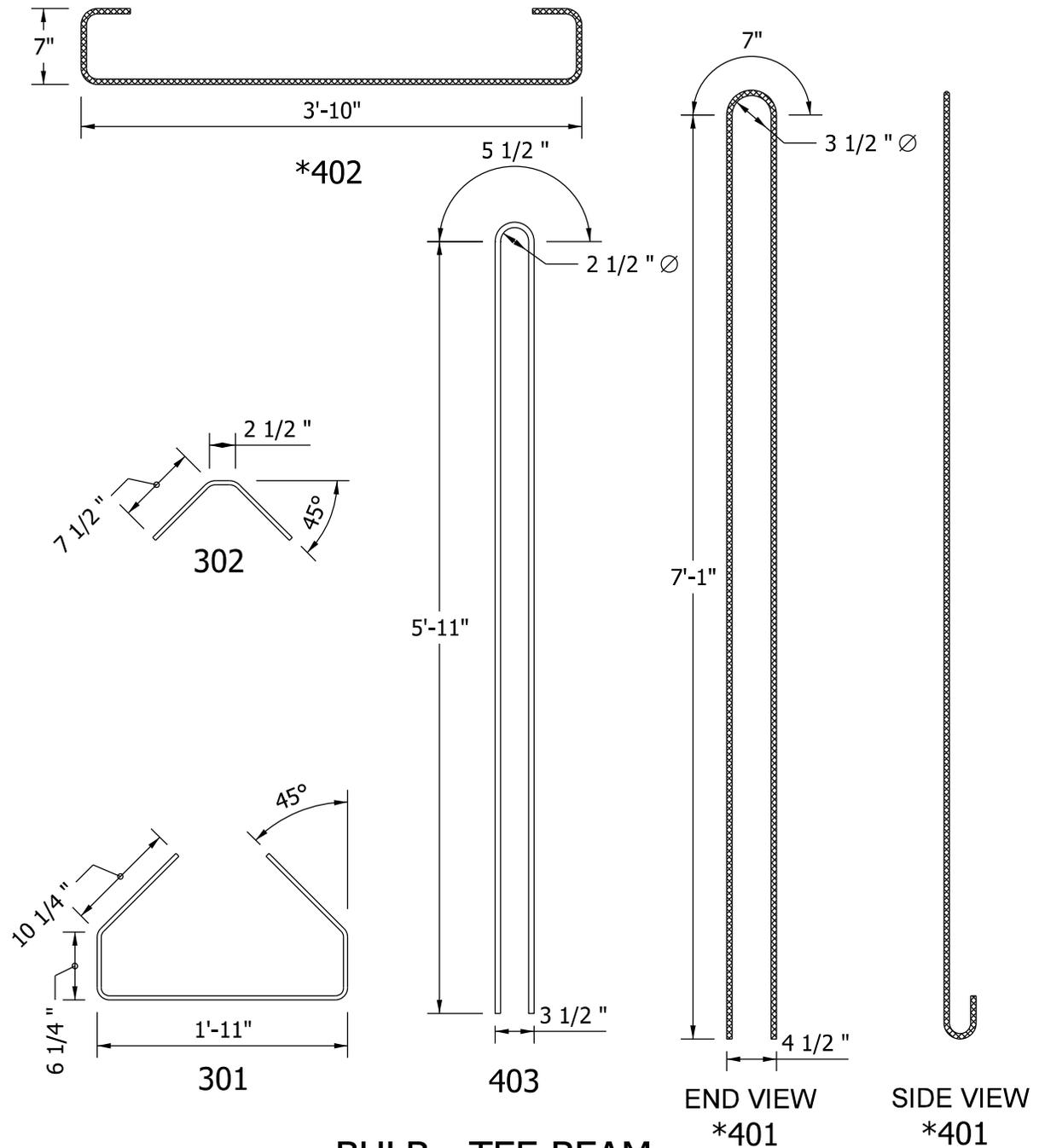
 * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 78 x 48
BAR BENDING DETAILS**

Figure 406-14E
(Page 2 of 2)

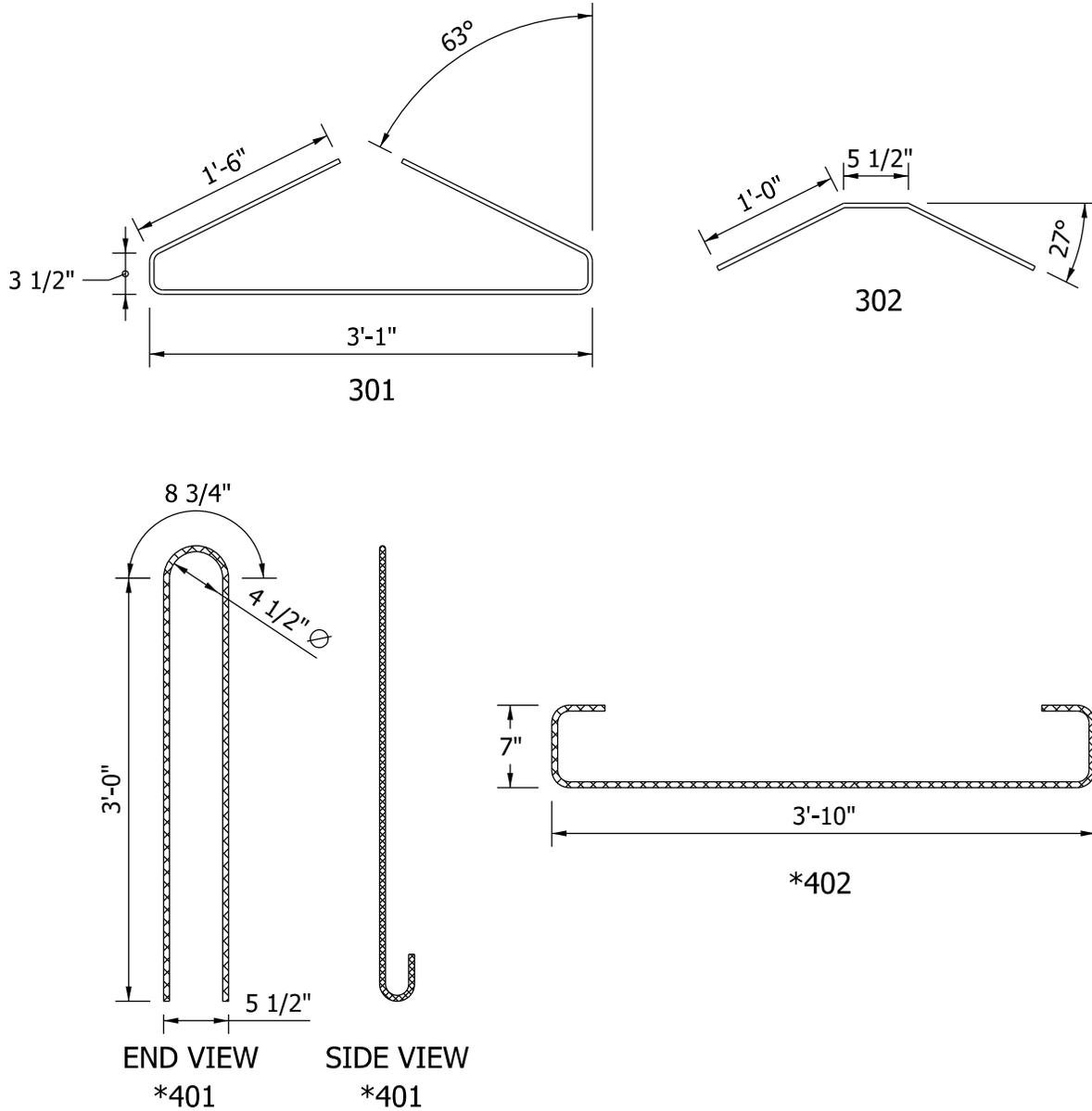
☒ * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 84 x 48
BAR BENDING DETAILS**

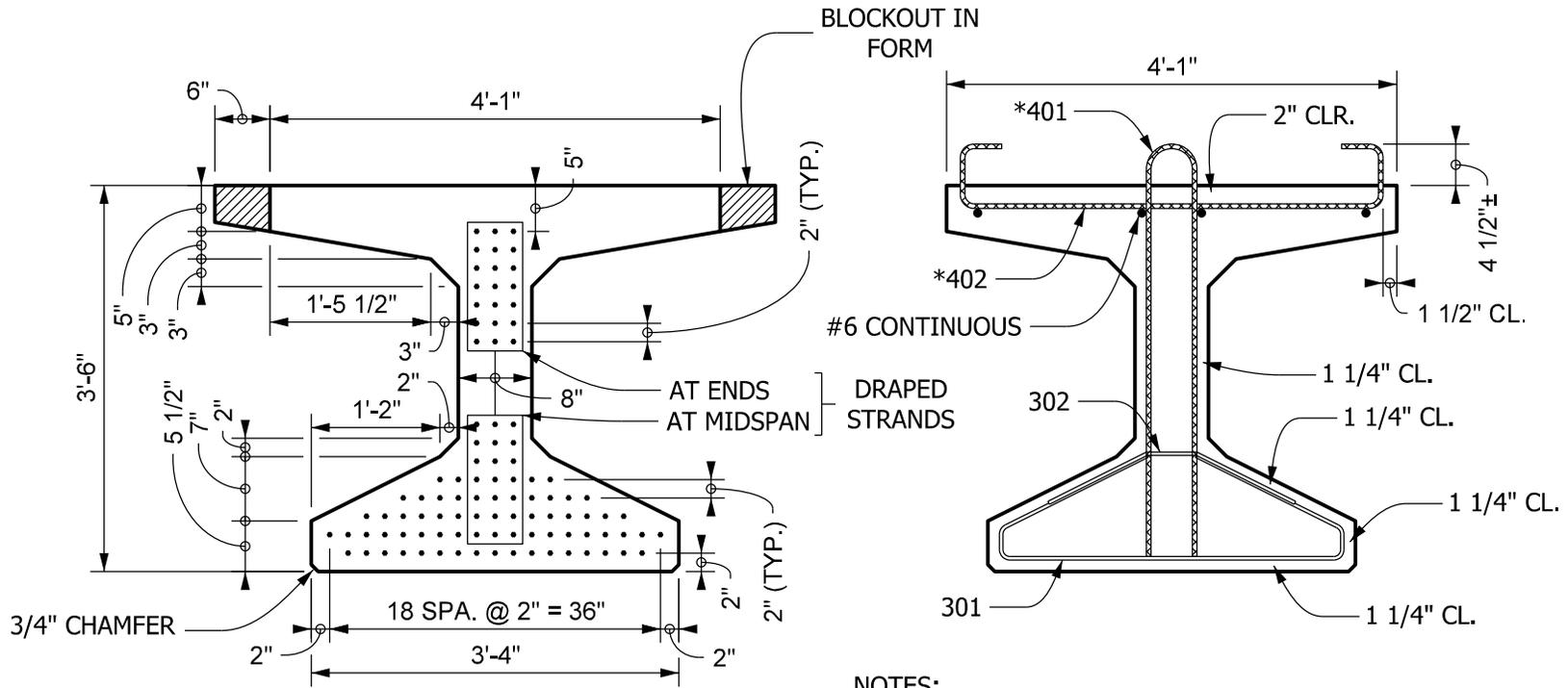
Figure 406-14F
(Page 2 of 2)

 * DENOTES EPOXY-COATED BARS



BULB-TEE BEAM TYPE BT 36 x 49 BAR BENDING DETAILS

Figure 406-14G
(Page 2 of 2)

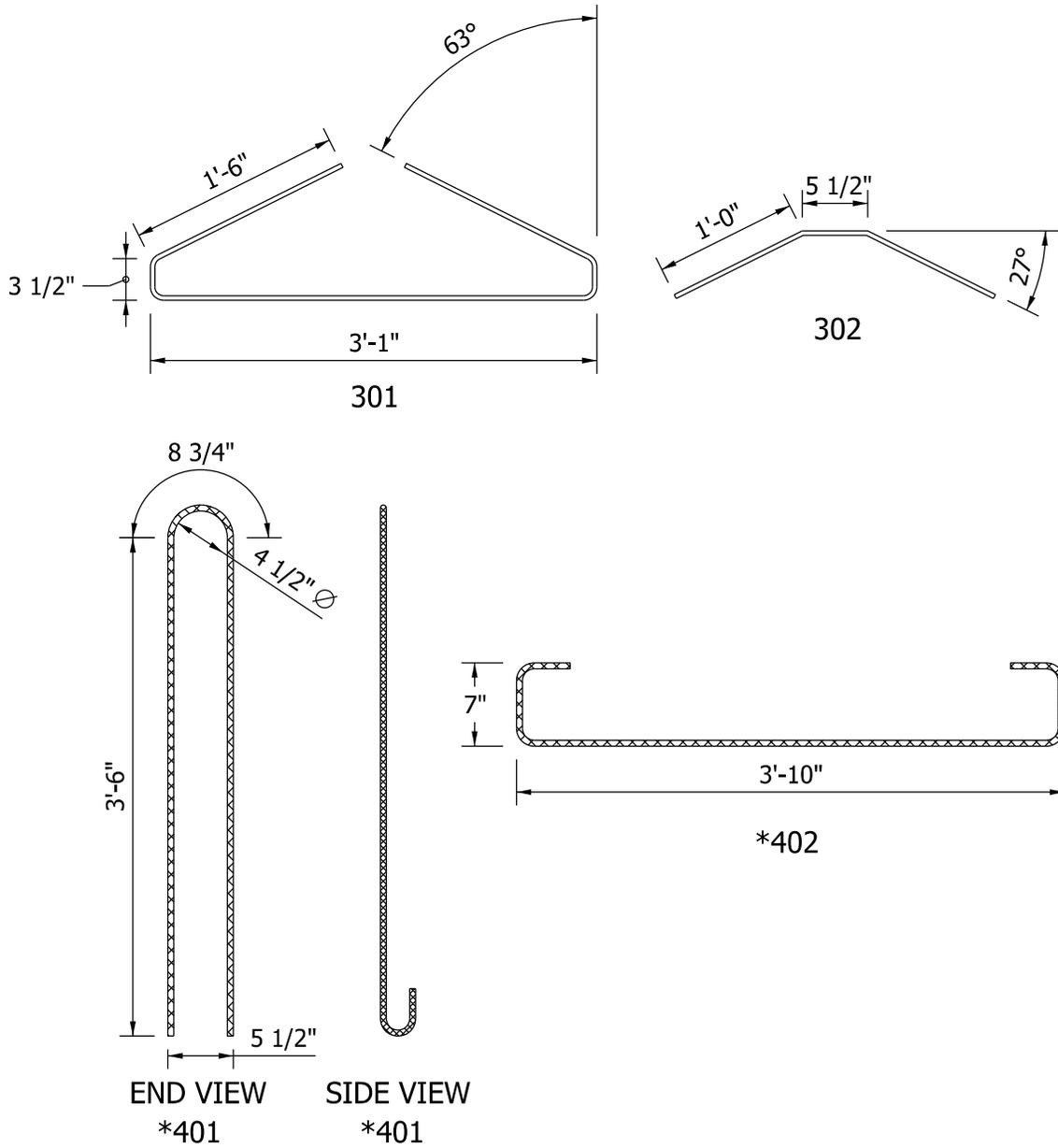


- NOTES:
1. *DENOTES EPOXY-COATED BARS.
 2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
 3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

**BULB-TEE BEAM TYPE BT 42 x 49
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

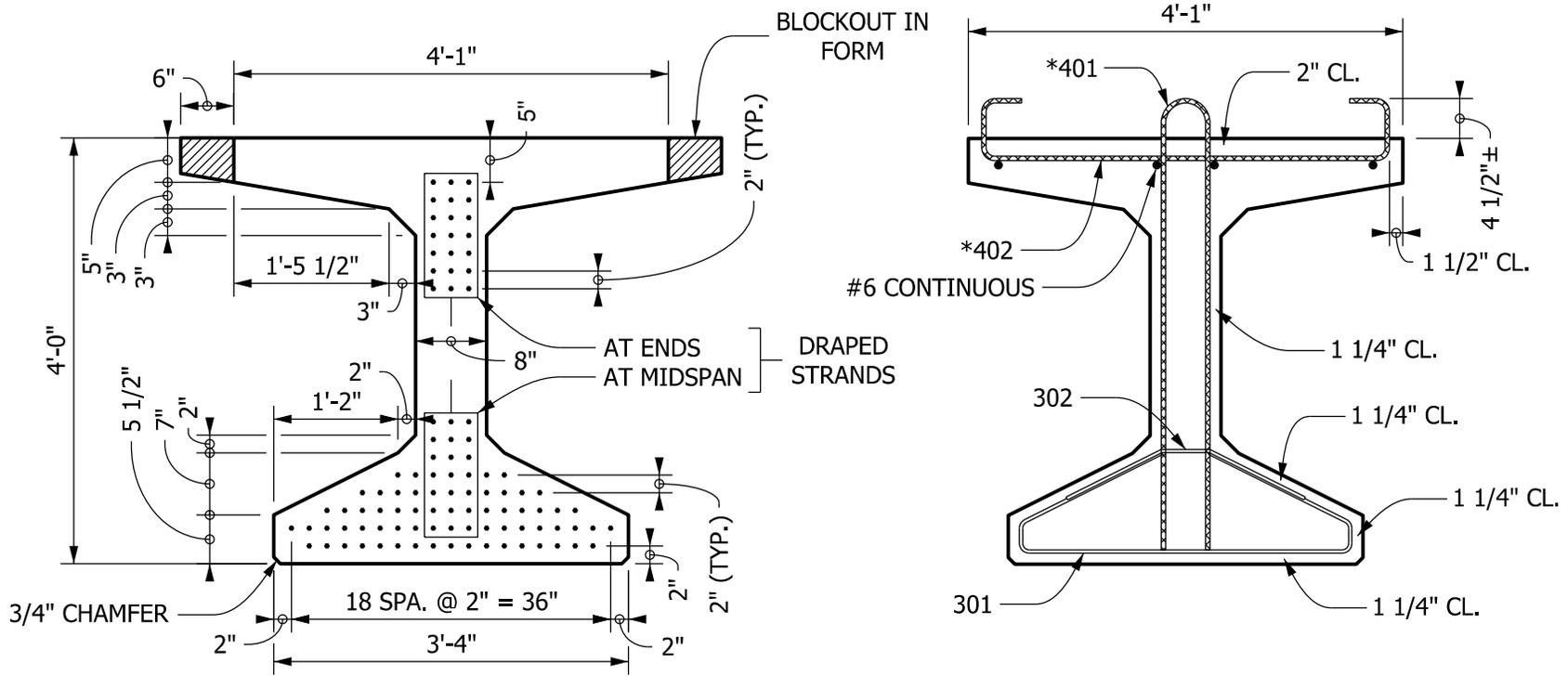
Figure 406-14H
(Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



BULB-TEE BEAM TYPE BT 42 x 49 BAR BENDING DETAILS

Figure 406-14H
(Page 2 of 2)

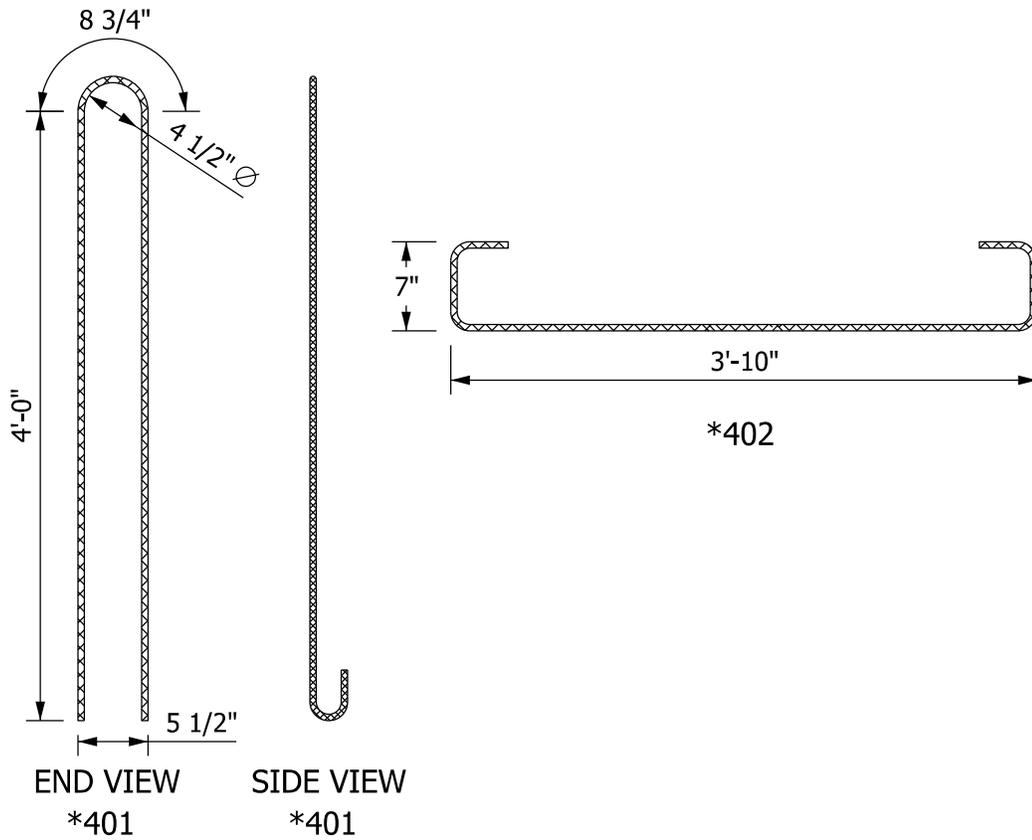
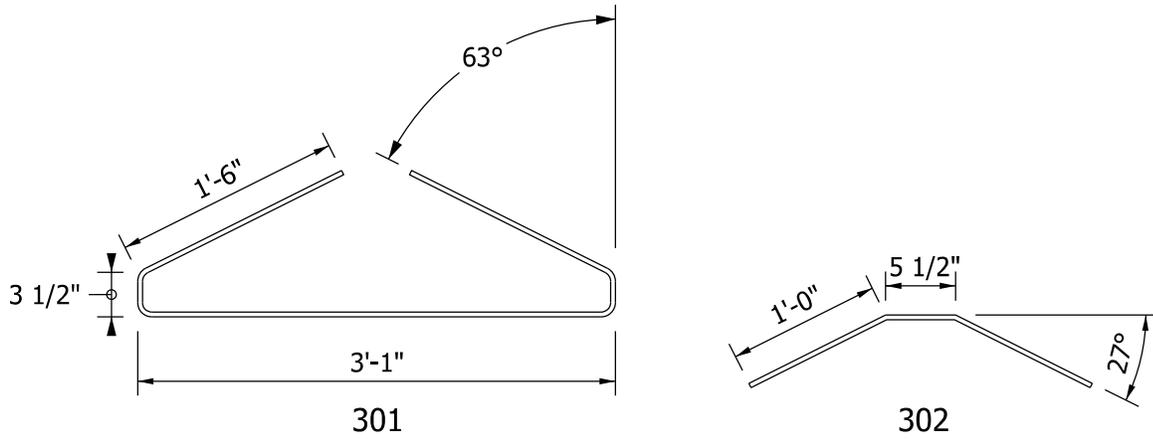


- NOTES:
1. *DENOTES EPOXY-COATED BARS.
 2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
 3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

**BULB-TEE BEAM TYPE BT 48 x 49
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

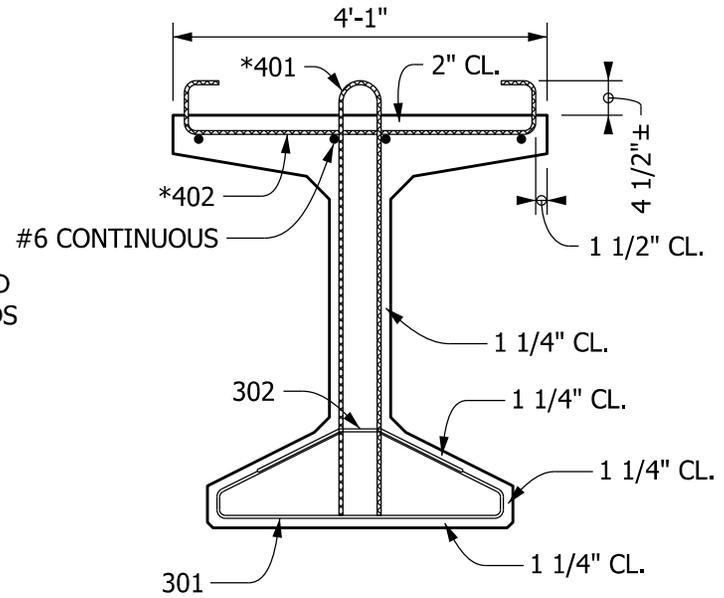
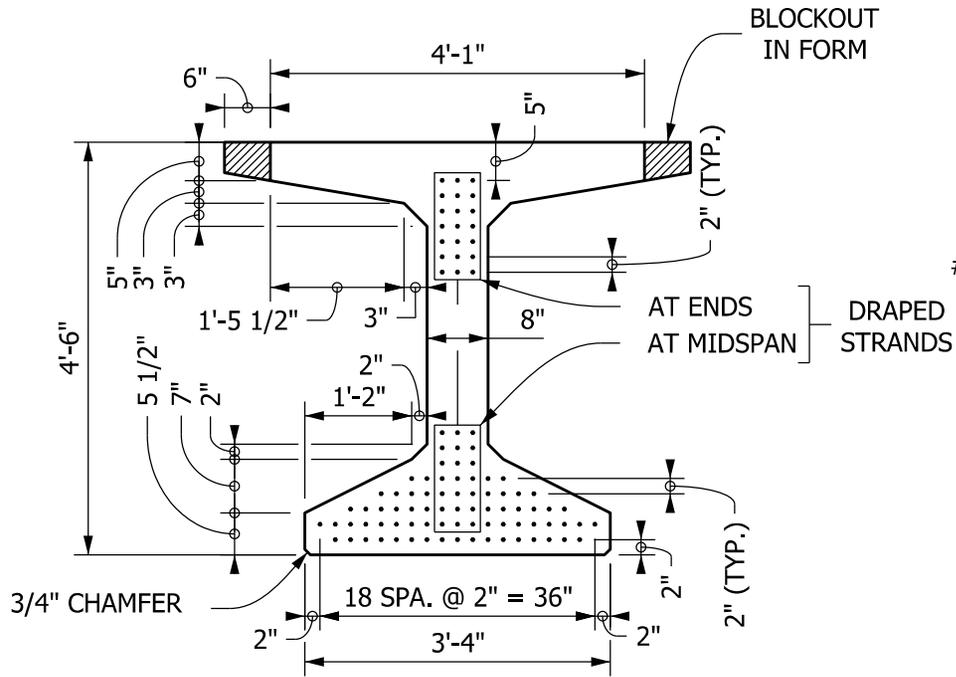
Figure 406-14 I
(Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



BULB-TEE BEAM TYPE BT 48 x 49 BAR BENDING DETAILS

Figure 406-14 I
(Page 2 of 2)

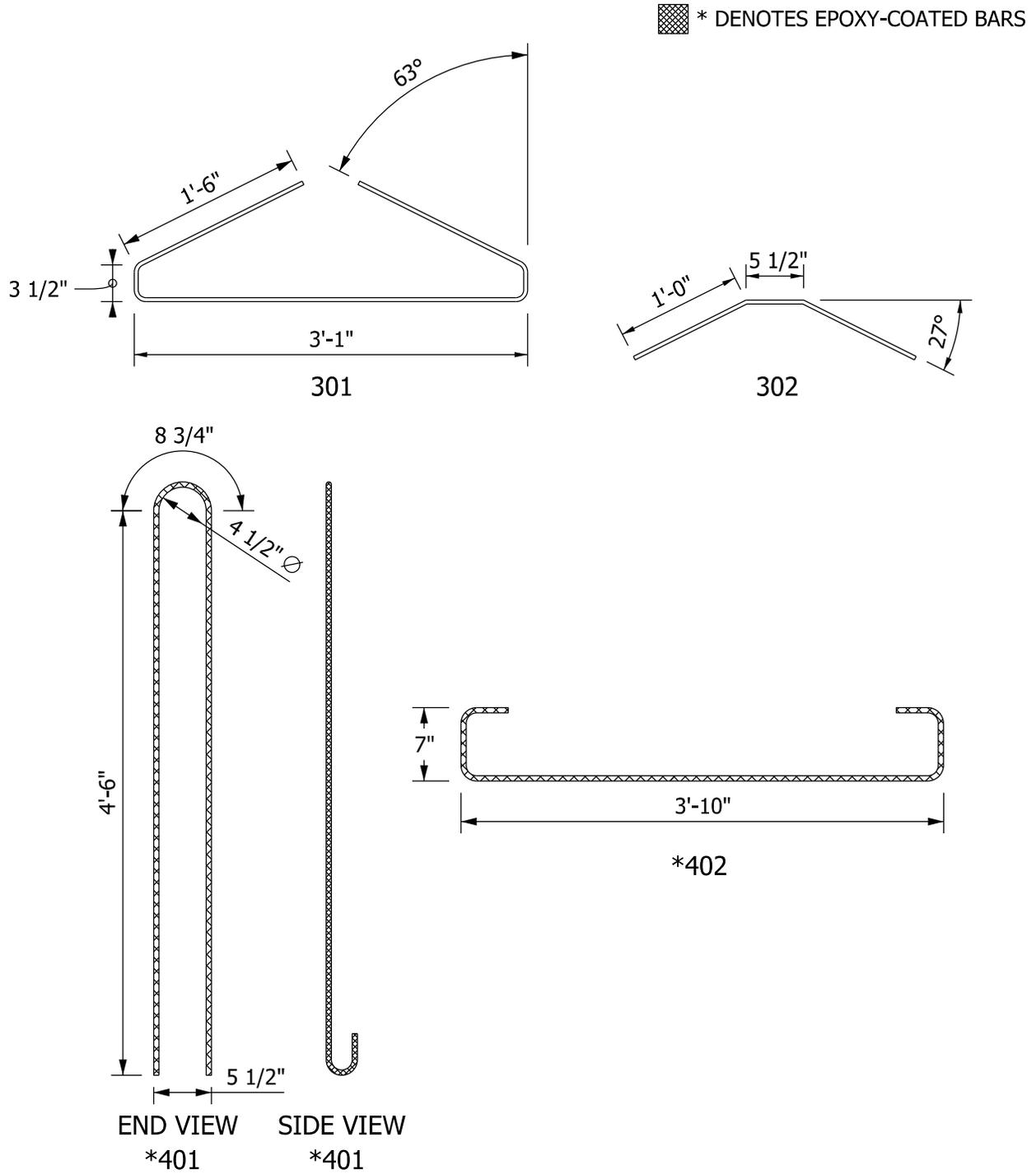


NOTES:

1. *DENOTES EPOXY-COATED BARS.
2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

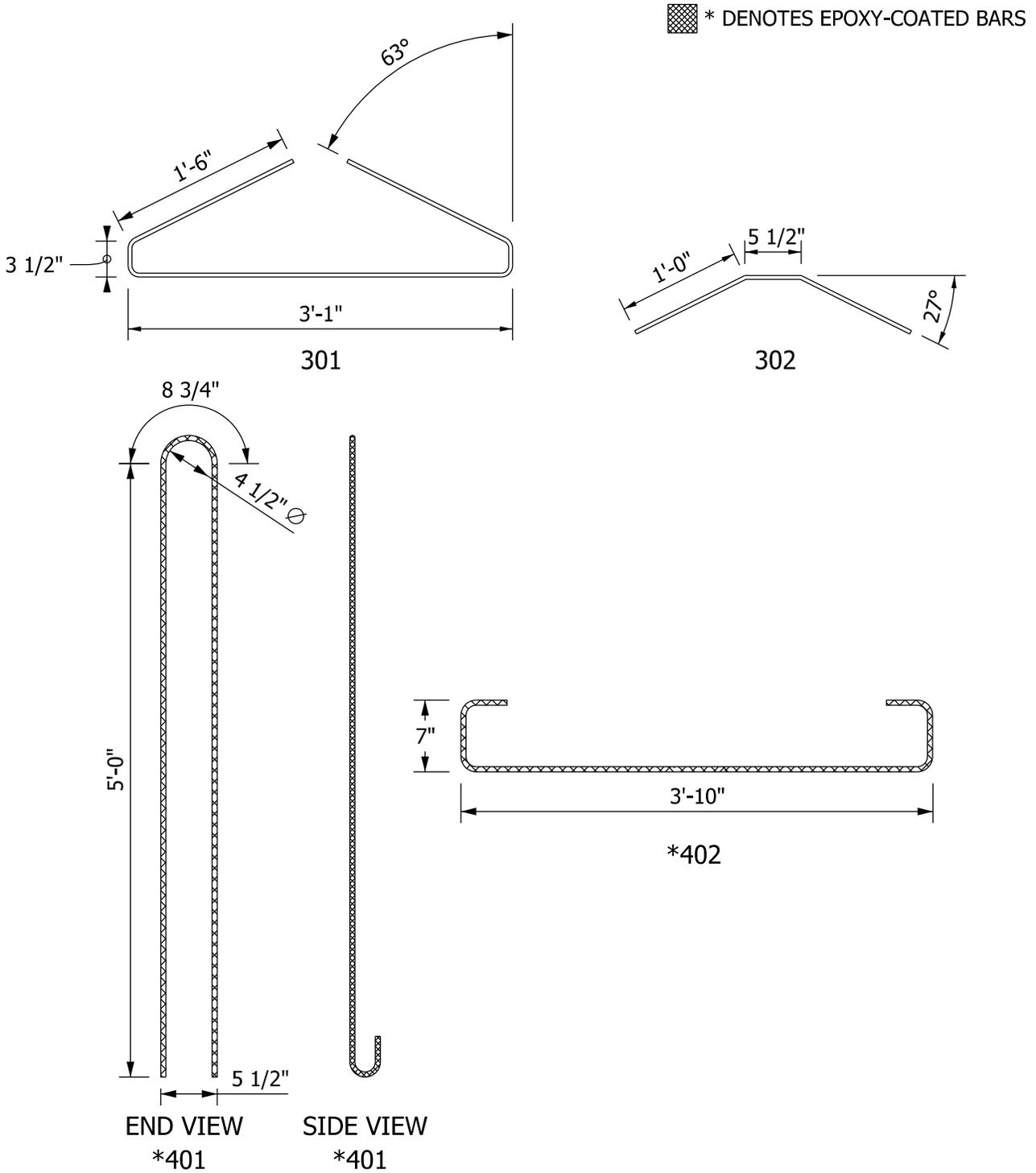
**BULB-TEE BEAM TYPE BT 54 x 49
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

Figure 406-14J
(Page 1 of 2)



BULB-TEE BEAM TYPE BT 54 x 49 BAR BENDING DETAILS

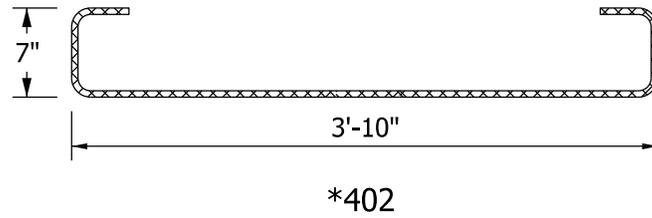
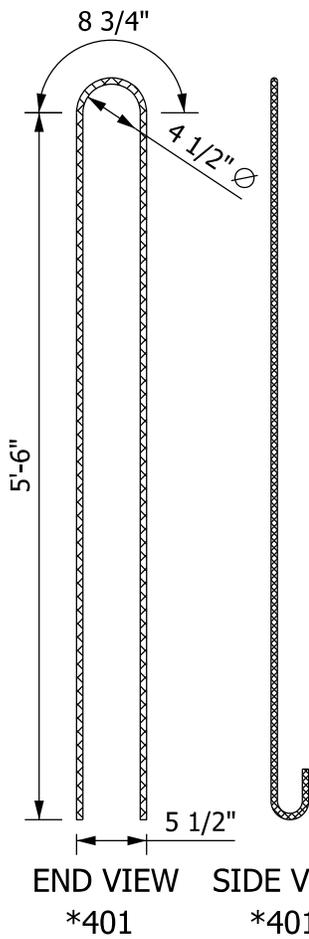
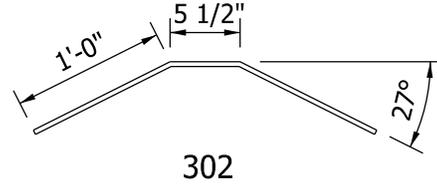
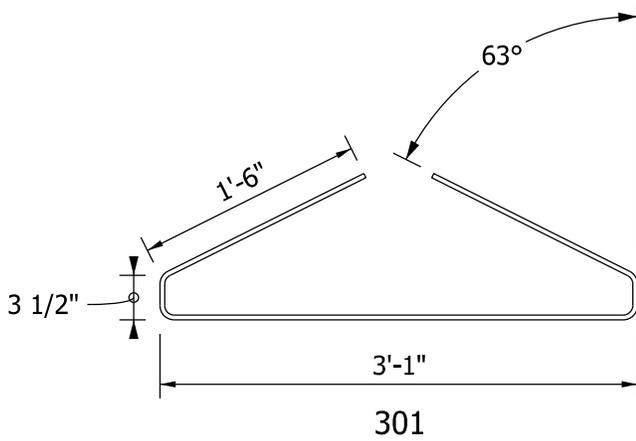
Figure 406-14J
(Page 2 of 2)



BULB-TEE BEAM TYPE BT 60 x 49 BAR BENDING DETAILS

Figure 406-14K
(Page 2 of 2)

 * DENOTES EPOXY-COATED BARS



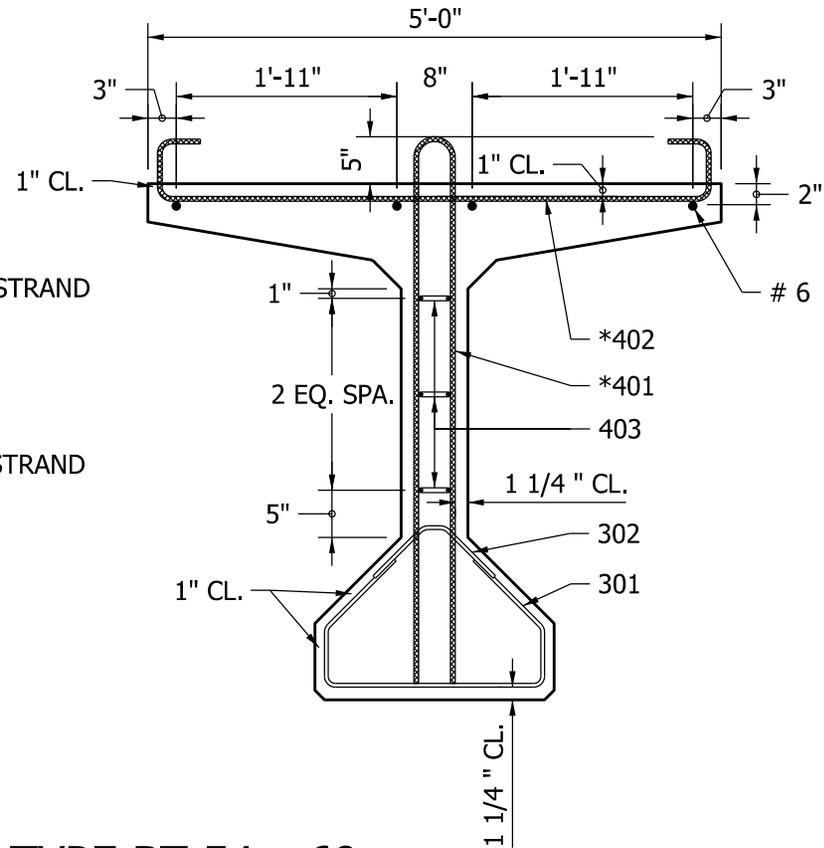
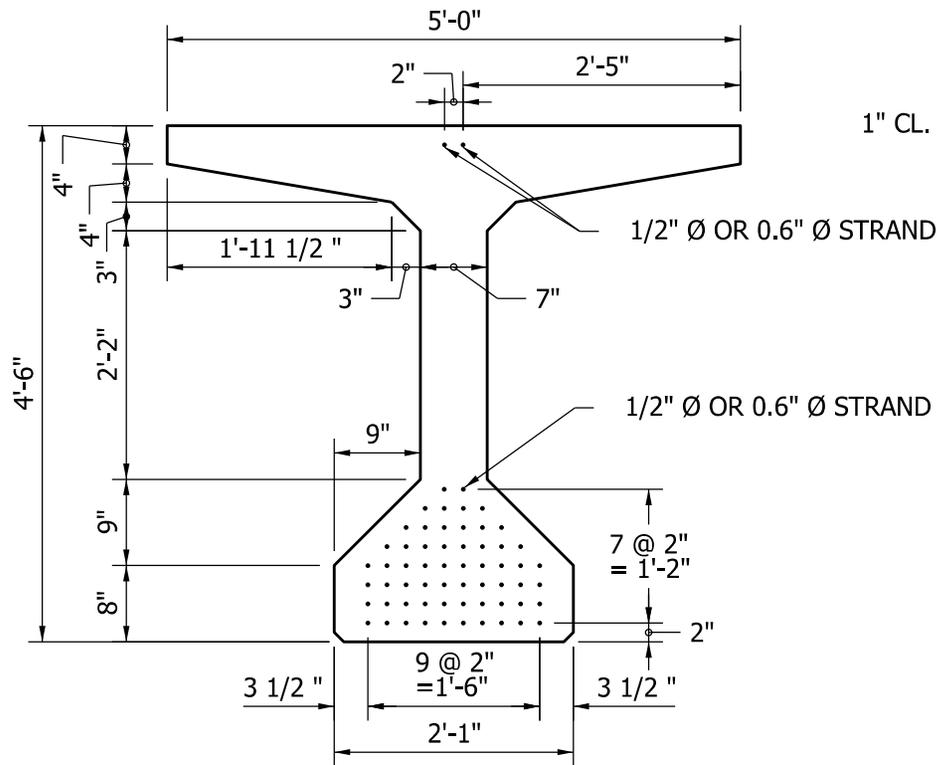
BULB-TEE BEAM TYPE BT 66 x 49 BAR BENDING DETAILS

Figure 406-14L
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 934 IN. ²
I_B	= 366,592 IN. ⁴
S_{TB}	= 15,590 IN. ³
S_{BB}	= 12,025 IN. ³
Y_{TB}	= 23.5 IN.
Y_{BB}	= 30.5 IN.
WT.	= 973 LB/LF

NOTES:

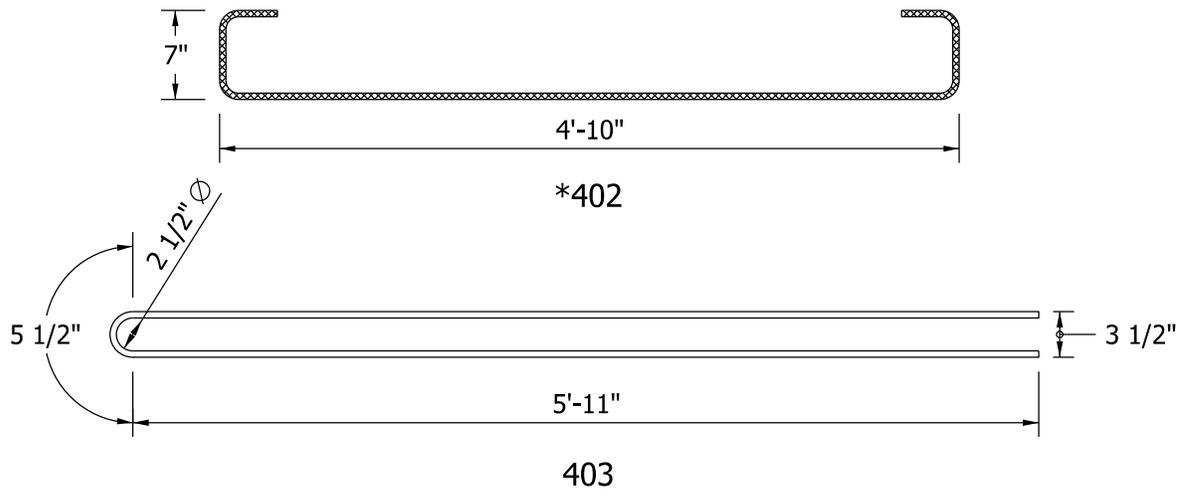
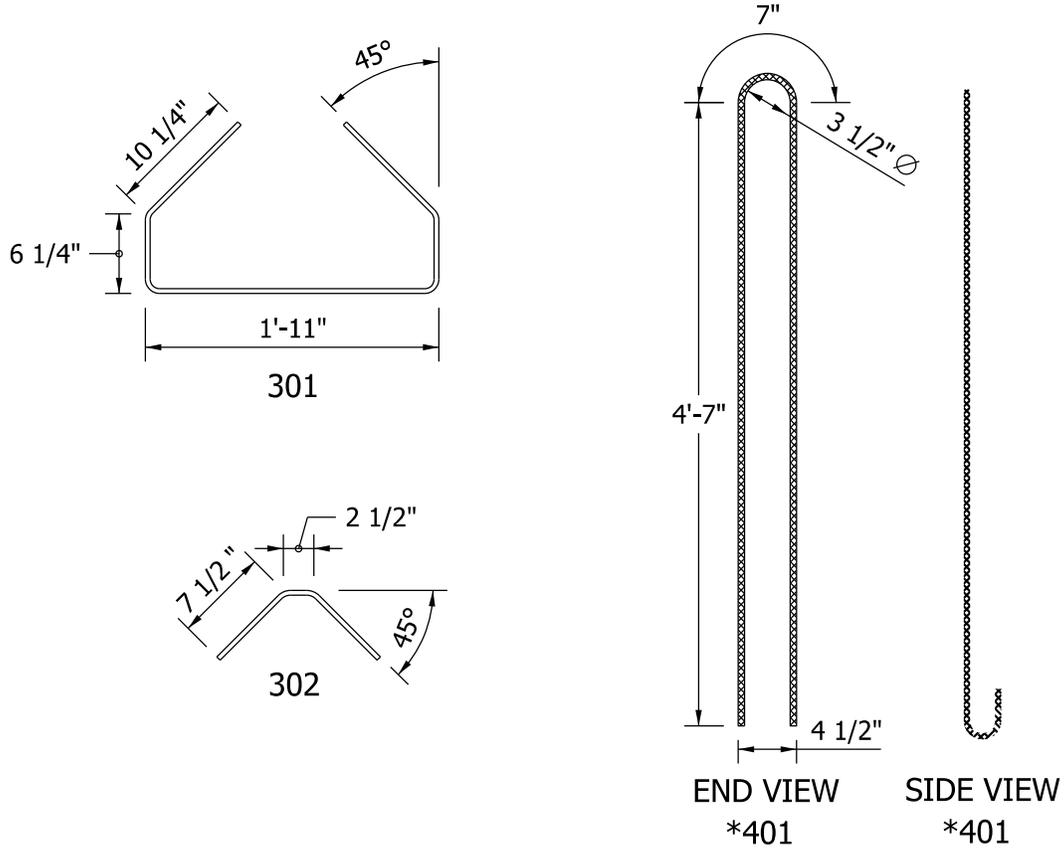
1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.
2. *DENOTES EPOXY-COATED BARS



BULB-TEE BEAM TYPE BT 54 x 60

Figure 406-14M
(Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



BULB-TEE BEAM TYPE BT 54 x 60 BAR BENDING DETAILS

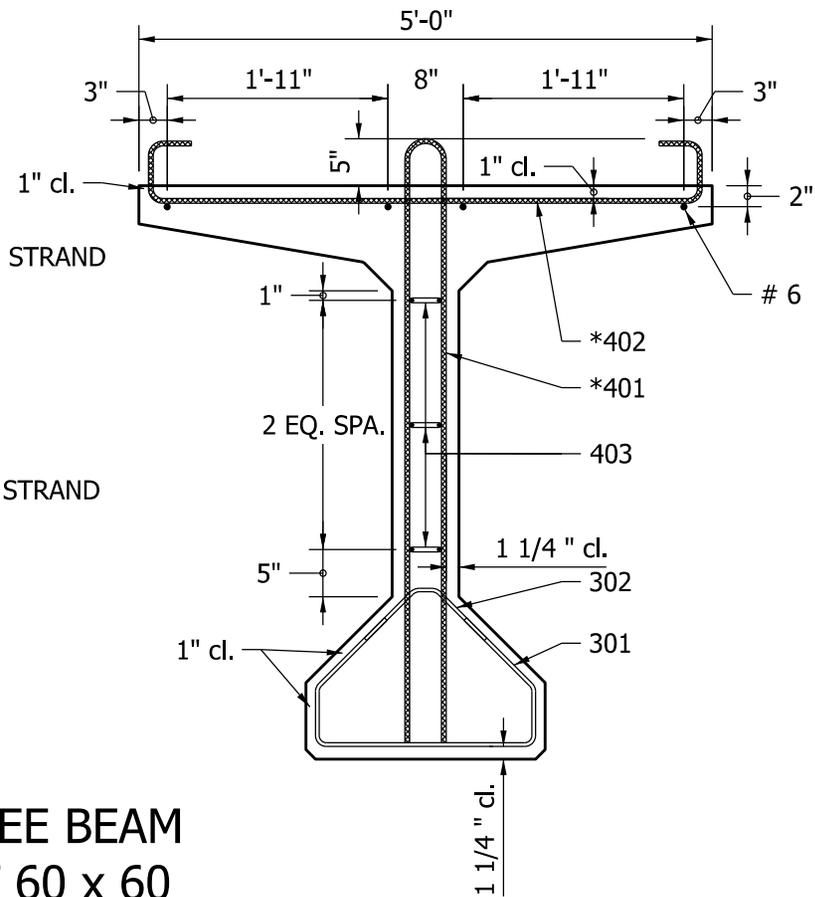
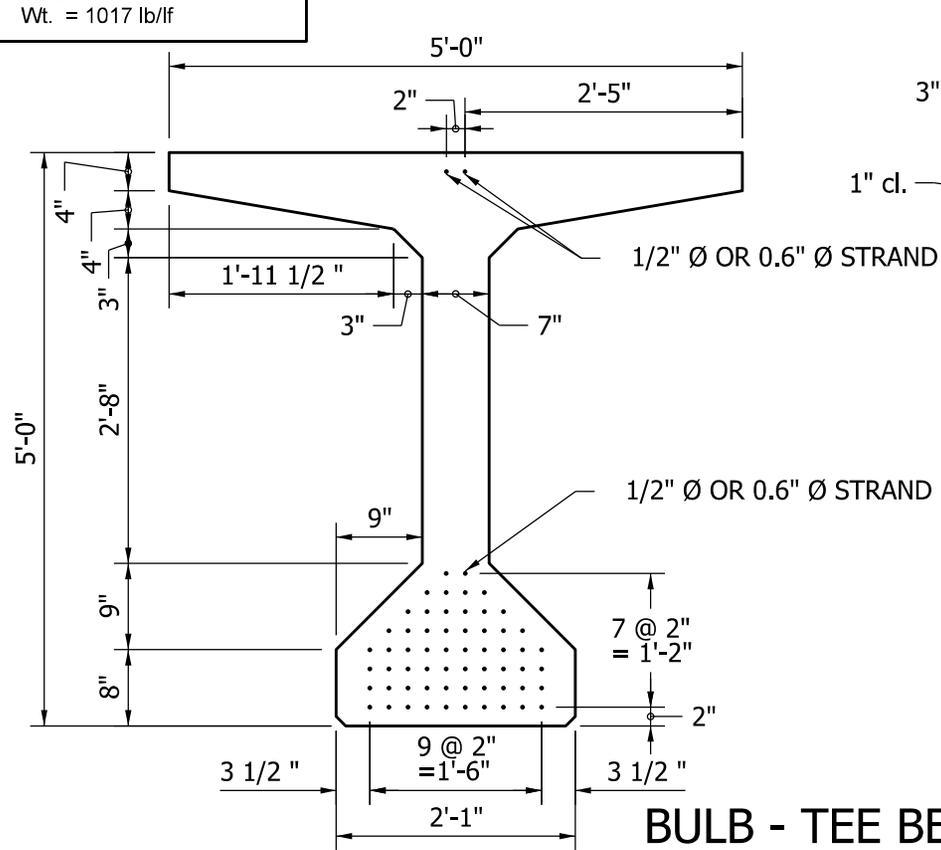
Figure 406-14M
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 976 in ²
I_B	= 478,833 in ²
S_{TB}	= 18,180 in ³
S_{BB}	= 14,223 in ³
Y_{TB}	= 26.3 in
Y_{BB}	= 33.7 in
Wt.	= 1017 lb/lf

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

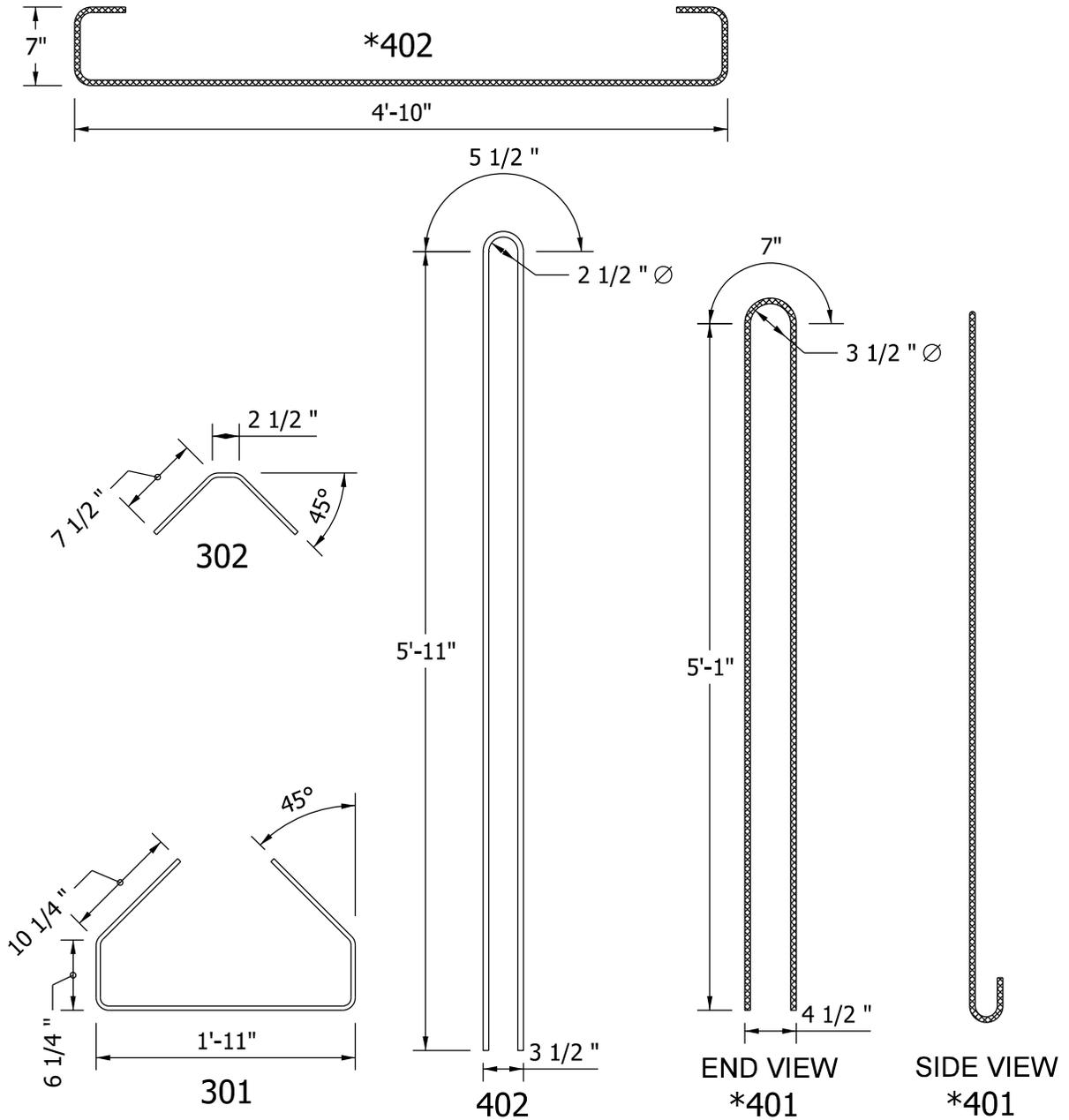
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
 TYPE BT 60 x 60**

Figure 406-14N
 (Page 1 of 2)

☒ * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 60 x 60
BAR BENDING DETAILS**

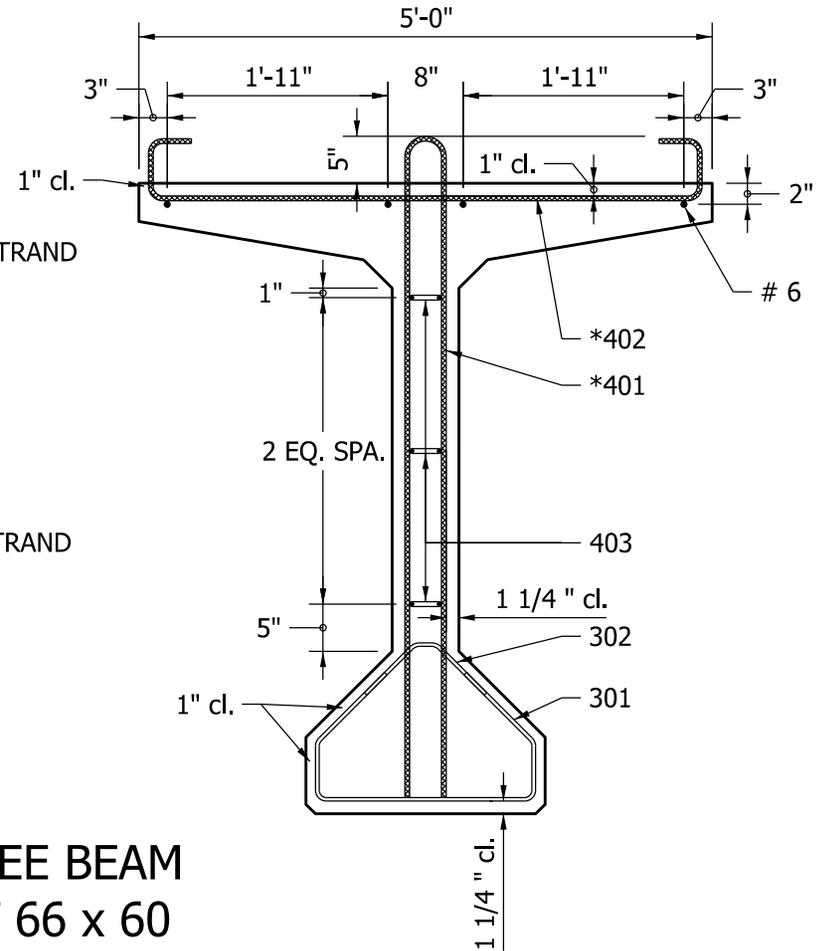
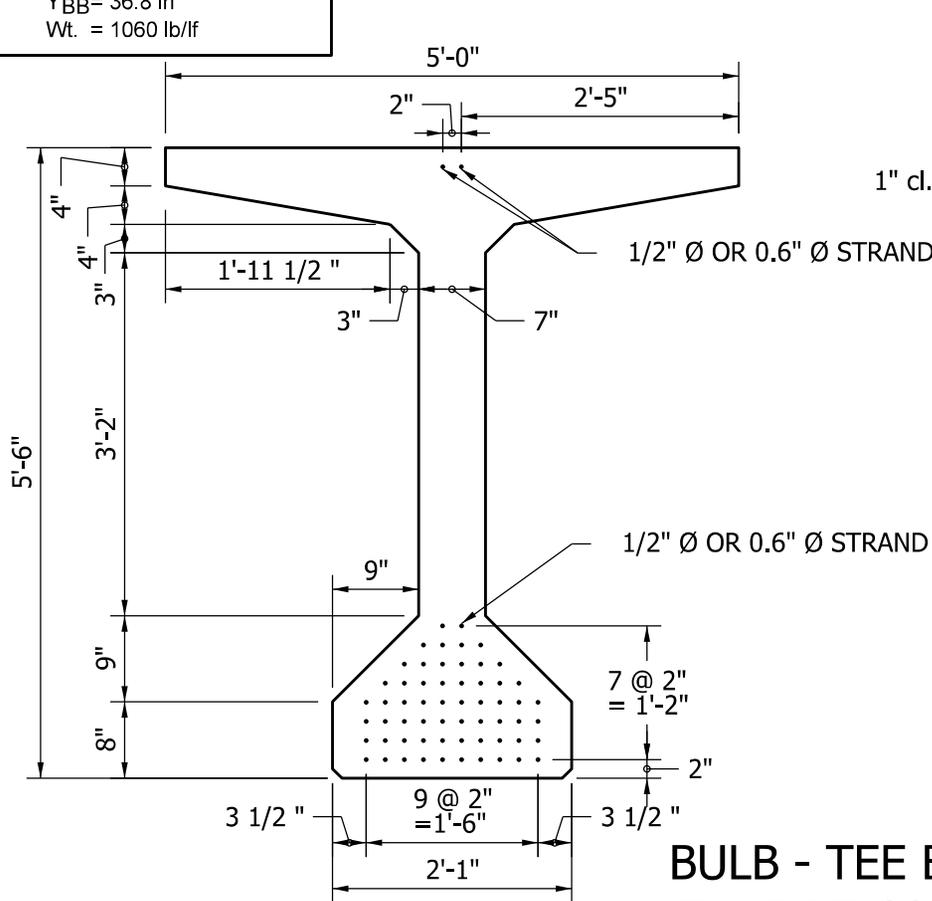
Figure 406-14N
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 1018 in ²
I_B	= 608,591 in ⁴
S_{TB}	= 20,859 in ³
S_{BB}	= 16,527 in ³
Y_{TB}	= 29.2 in
Y_{BB}	= 36.8 in
Wt.	= 1060 lb/lf

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

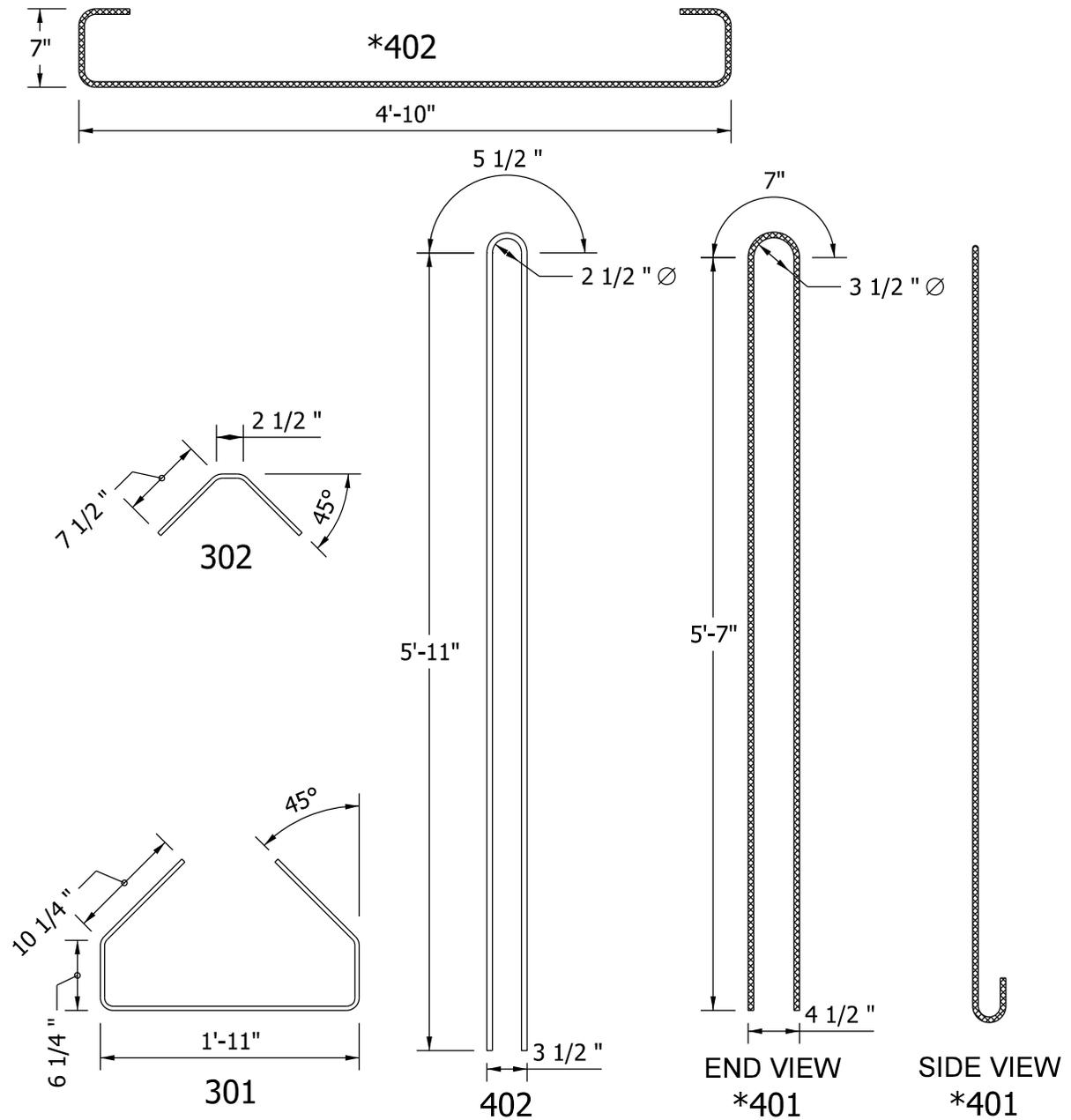
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 66 x 60**

Figure 406-14 O
(Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 66 x 60
BAR BENDING DETAILS**

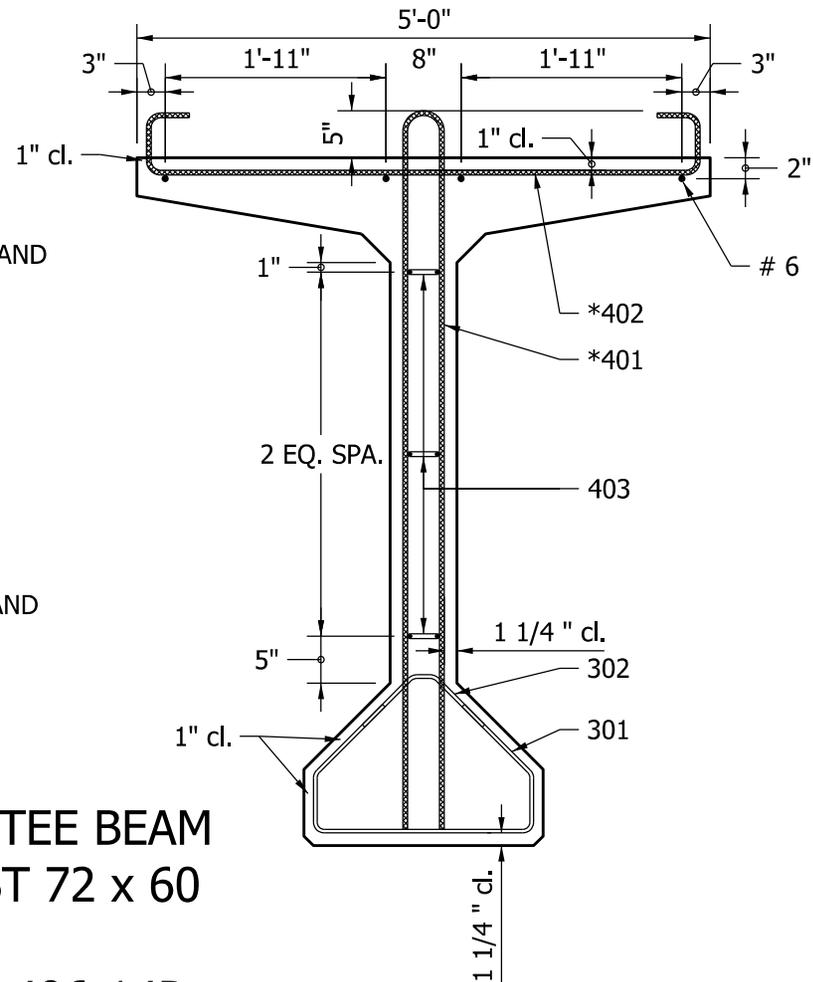
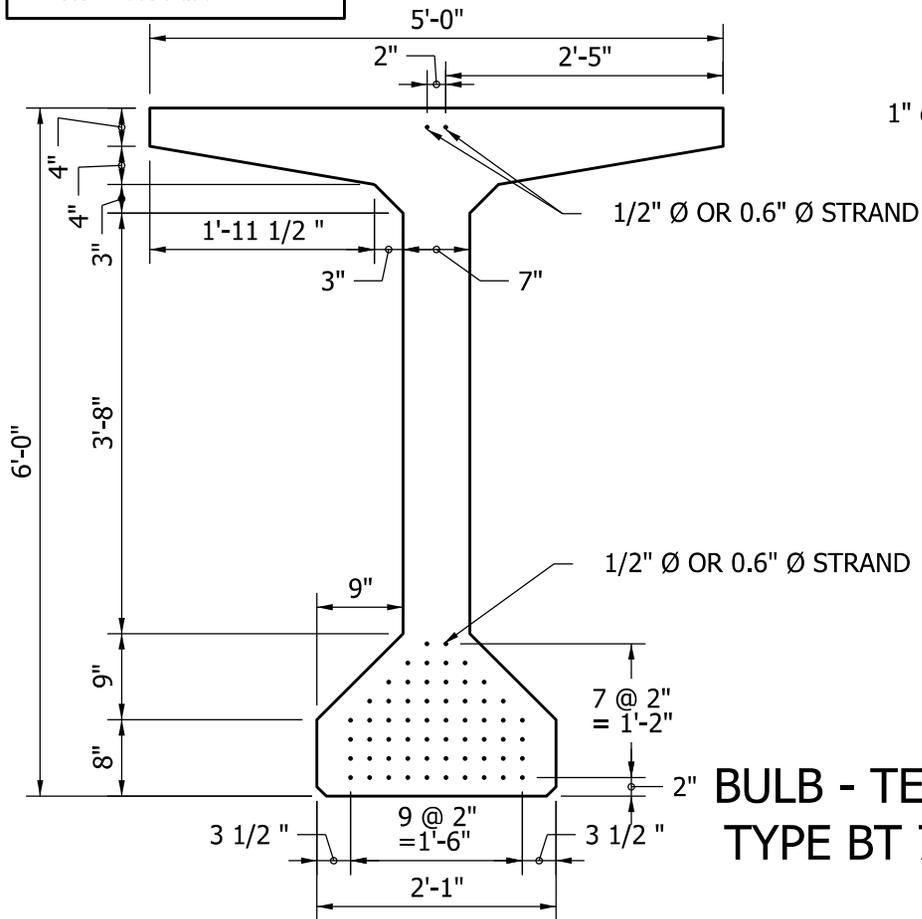
Figure 406-14 O
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 1060 in ²
I_B	= 756,629 in ²
S_{TB}	= 23,625 in ³
S_{BB}	= 18,929 in ³
Y_{TB}	= 32.0 in
Y_{BB}	= 40.0 in
Wt.	= 1104 lb/lf

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

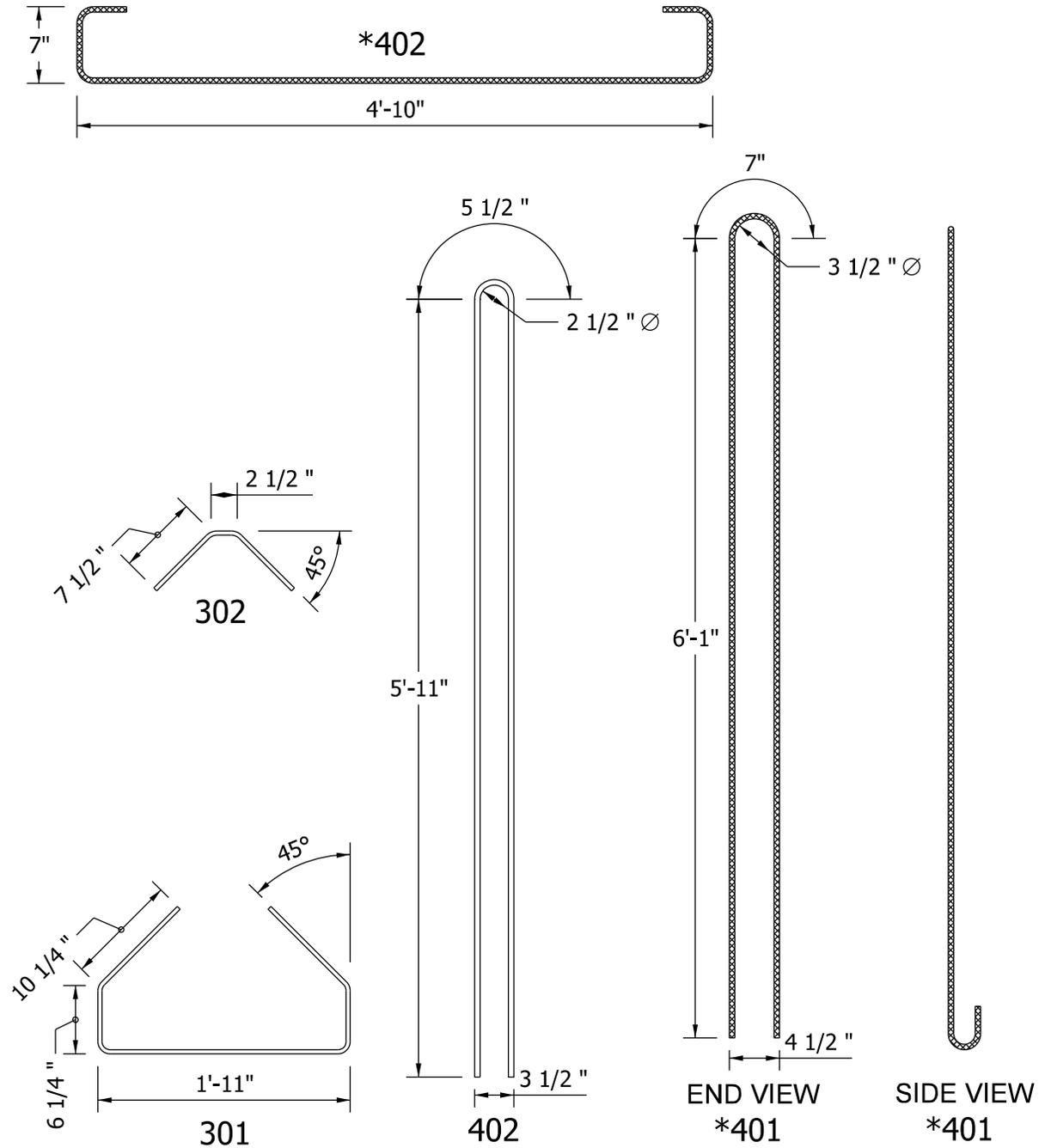
2. *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 72 x 60**

**Figure 406-14P
(Page 1 of 2)**

☒ * DENOTES EPOXY-COATED BARS

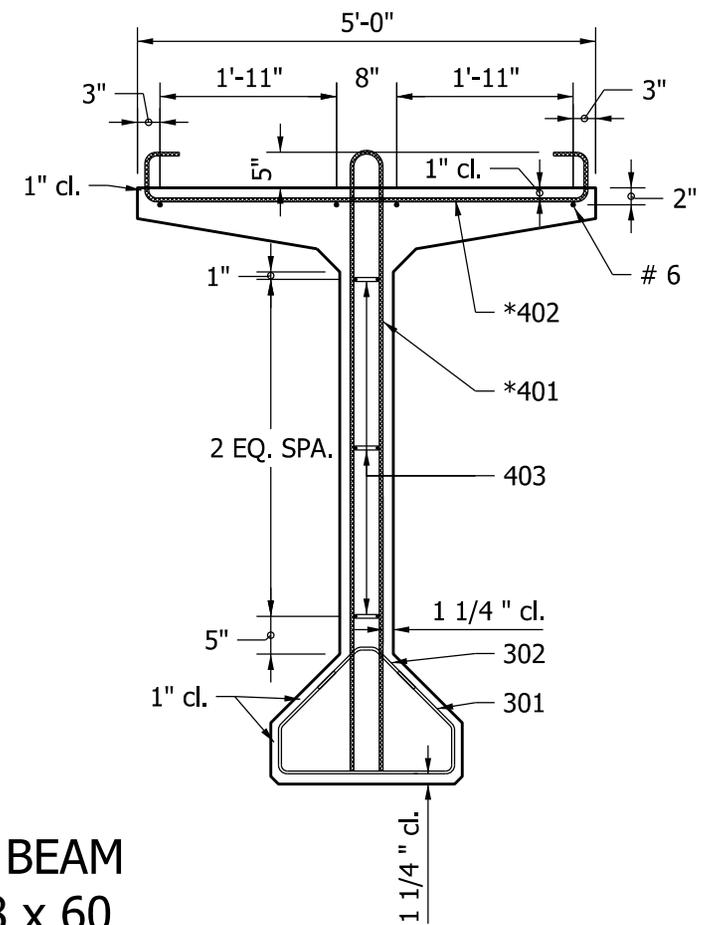
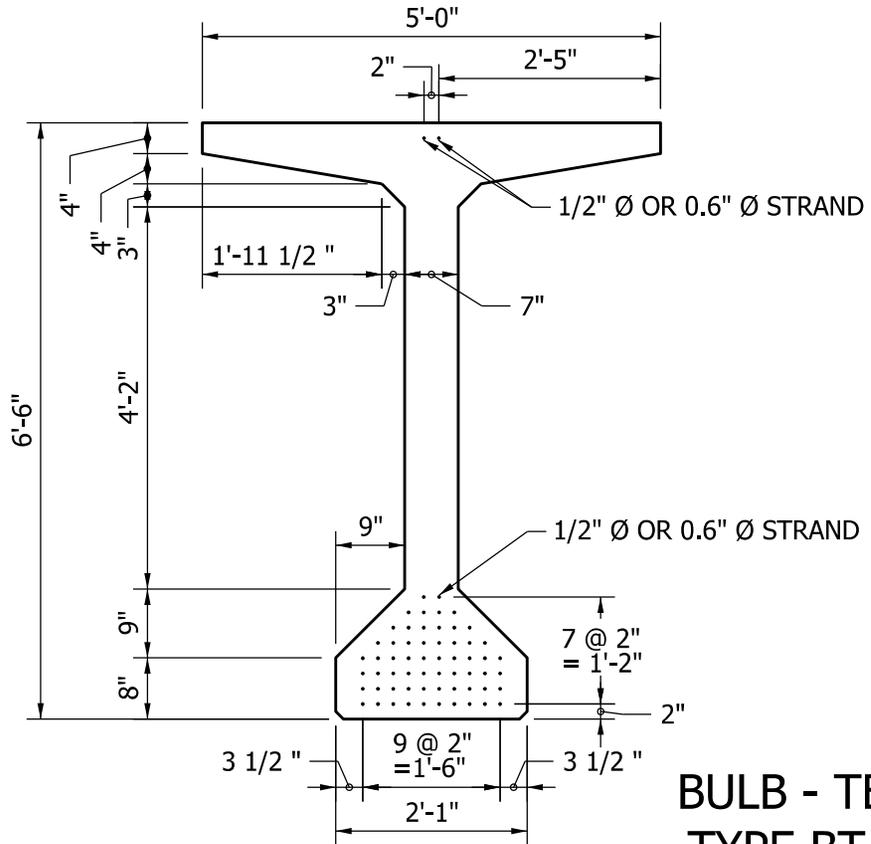


**BULB - TEE BEAM
TYPE BT 72 x 60
BAR BENDING DETAILS**

Figure 406-14P
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 1102 in ²
I_B	= 923,707 in ²
S_{TB}	= 26,475 in ³
S_{BB}	= 21,426 in ³
Y_{TB}	= 34.9 in
Y_{BB}	= 43.1 in
Wt.	= 1148 lb/lf

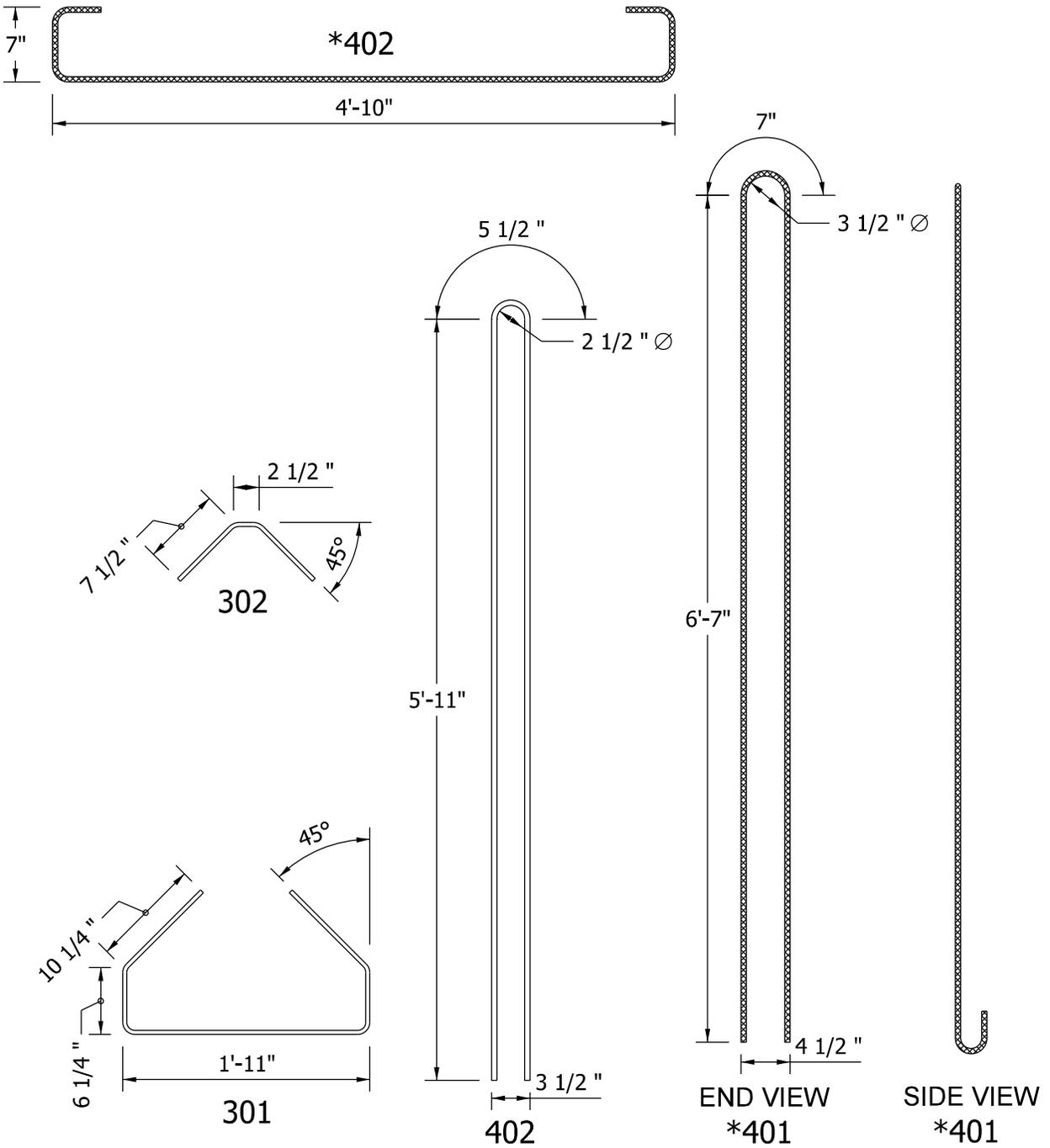
- NOTES:
1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.
 2.  *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 78 x 60**

**Figure 406-14Q
(Page 1 of 2)**

☒ * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 78 x 60
BAR BENDING DETAILS**

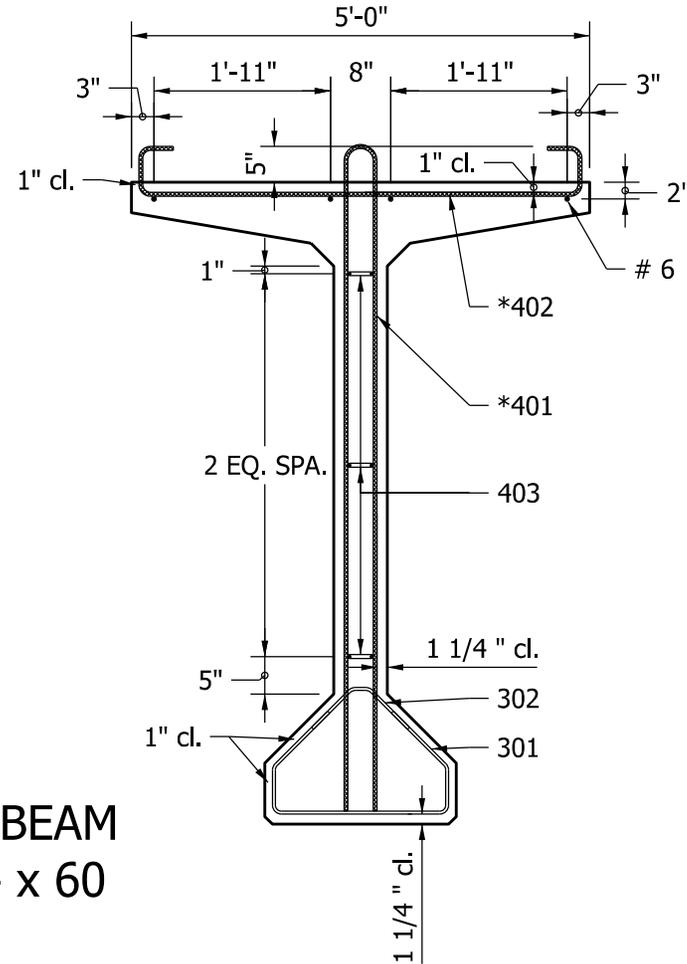
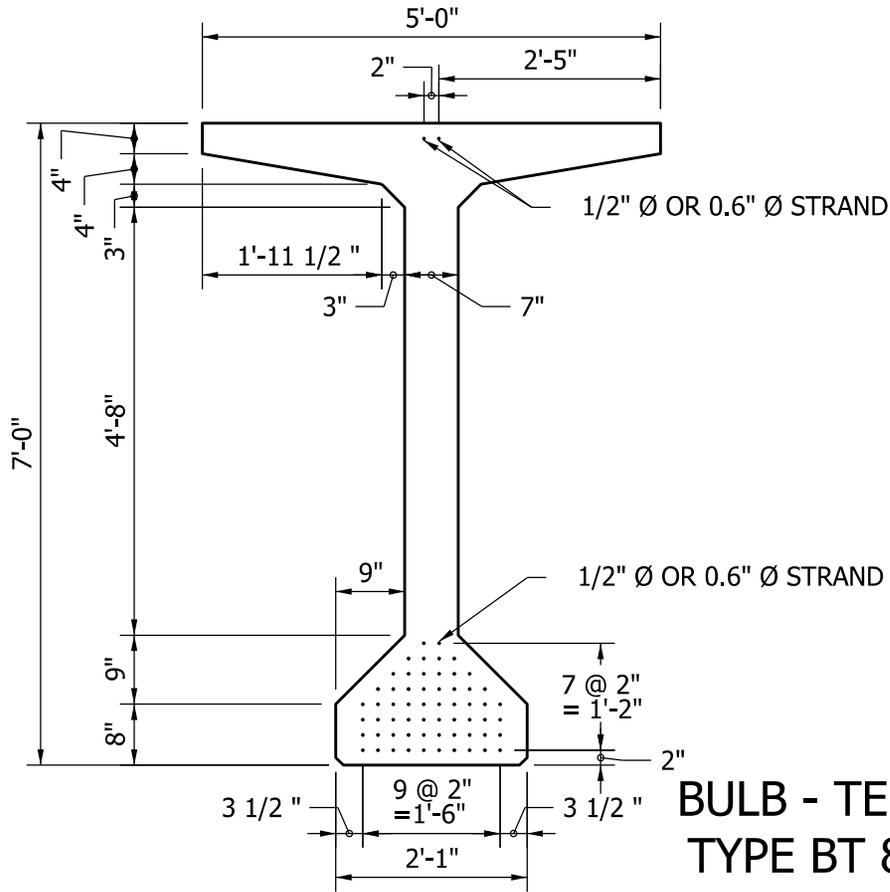
Figure 406-14Q
(Page 2 of 2)

BEAM PROPERTIES	
A_B	= 1144 in ²
I_B	= 1,110,587 in ²
S_{TB}	= 29,410 in ³
S_{BB}	= 24,019 in ³
Y_{TB}	= 37.8 in
Y_{BB}	= 46.2 in
Wt.	= 1192 lb/ft

NOTES:

1. BARS 301 AND 302 COMBINED TO FORM ONE STIRRUP.

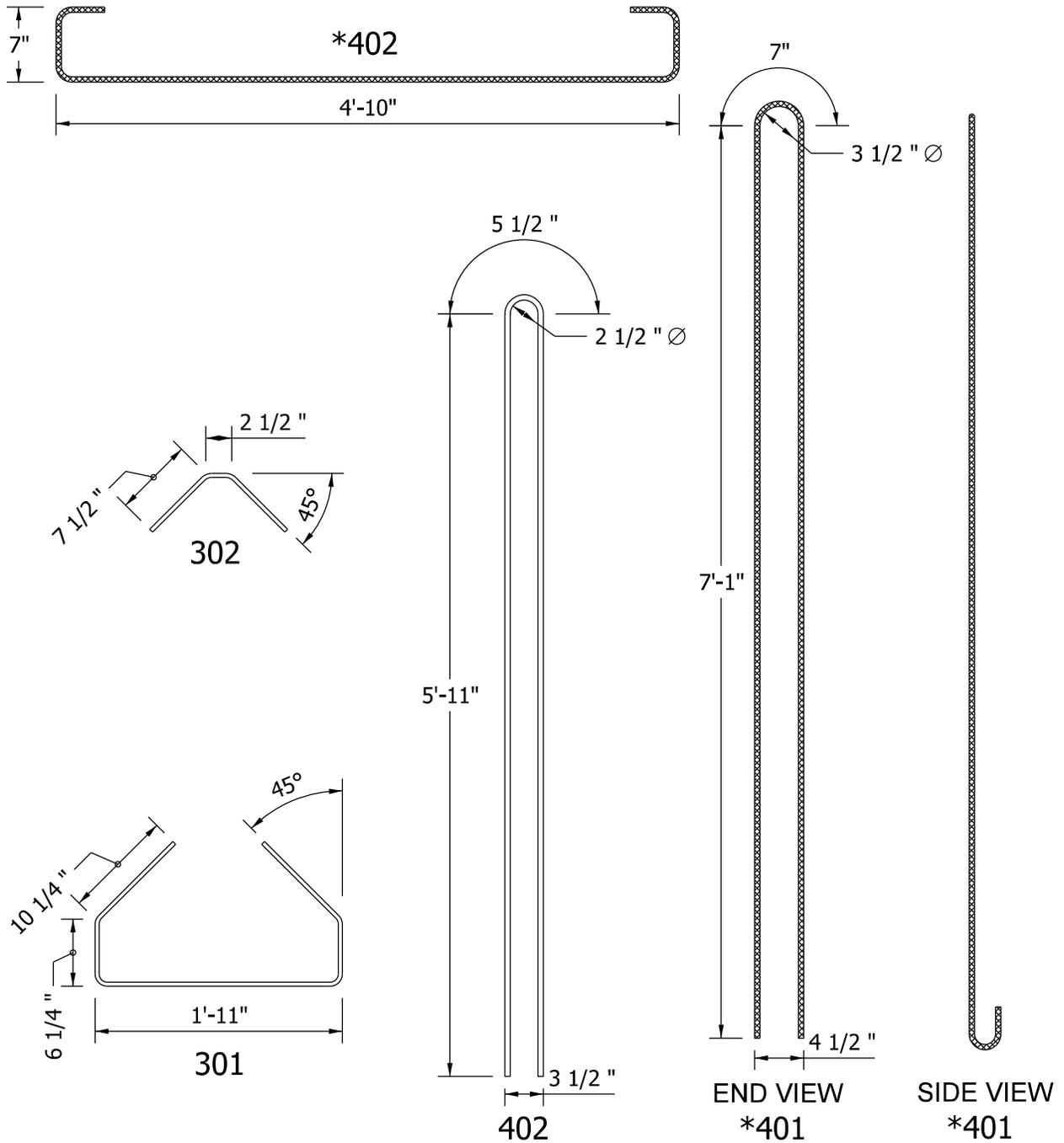
2.  *DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 84 x 60**

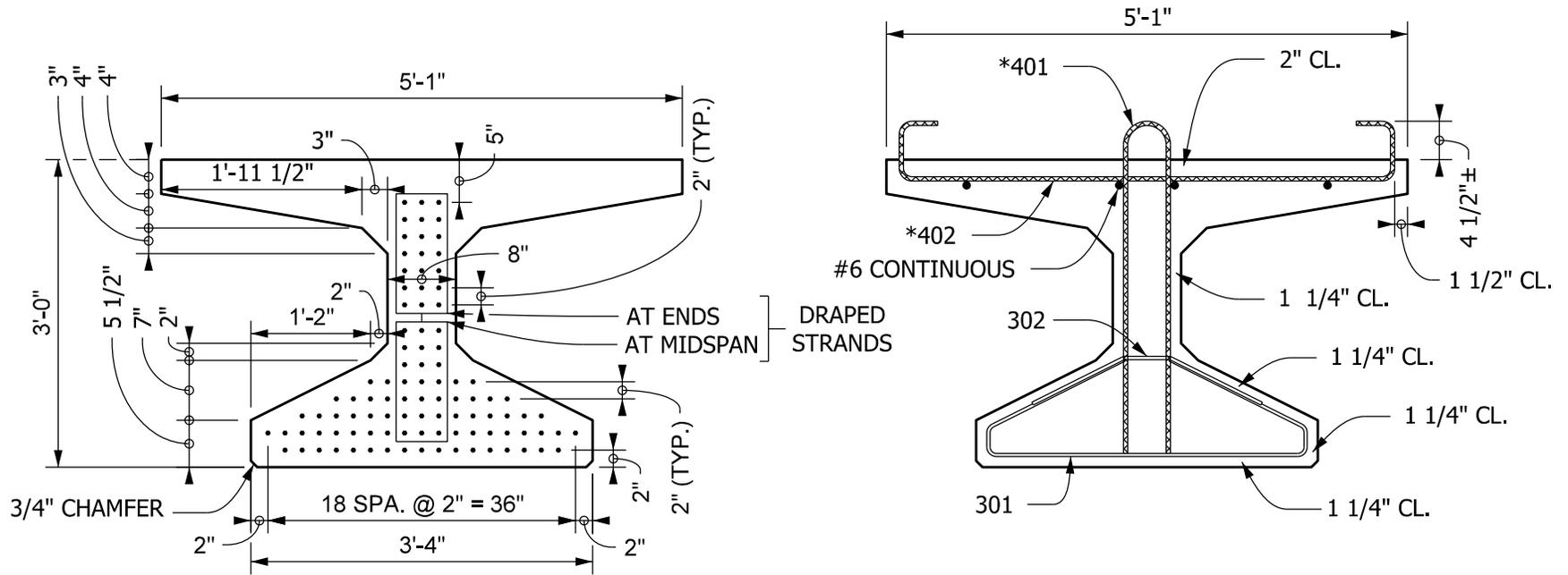
Figure 406-14R
(Page 1 of 2)

☒ * DENOTES EPOXY-COATED BARS



**BULB - TEE BEAM
TYPE BT 84 x 60
BAR BENDING DETAILS**

Figure 406-14R
(page 2 of 2)



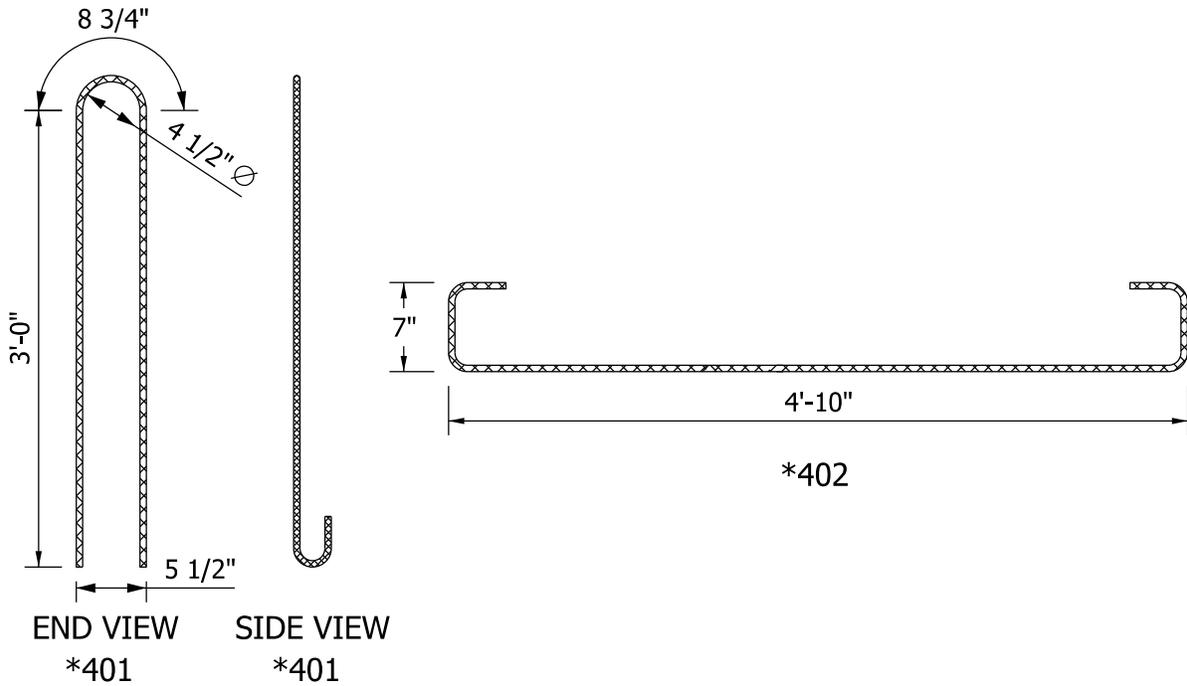
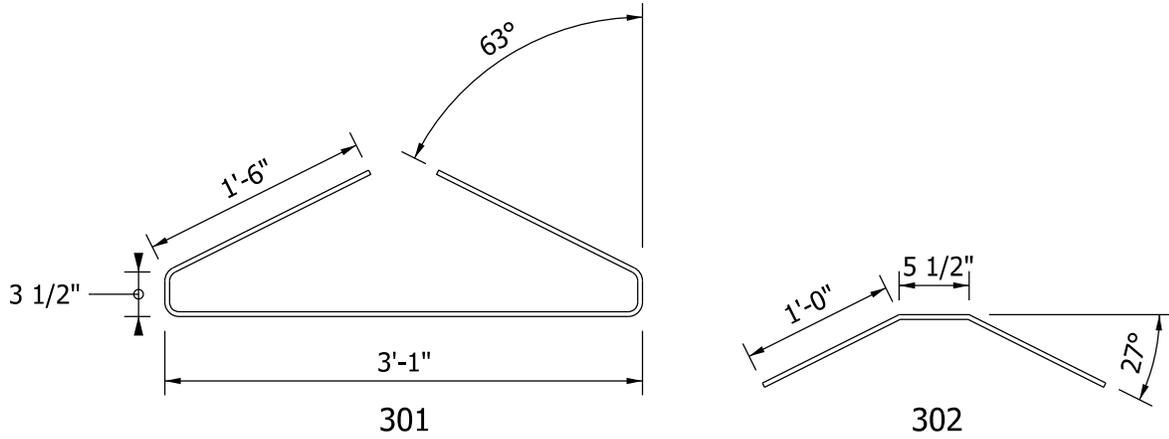
NOTES:

1. *DENOTES EPOXY-COATED BARS.
2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

WIDE BULB-TEE BEAM TYPE BT 36 x 61
 SECTIONS SHOWING PRESTRESSING
 AND MILD REINFORCING STEEL

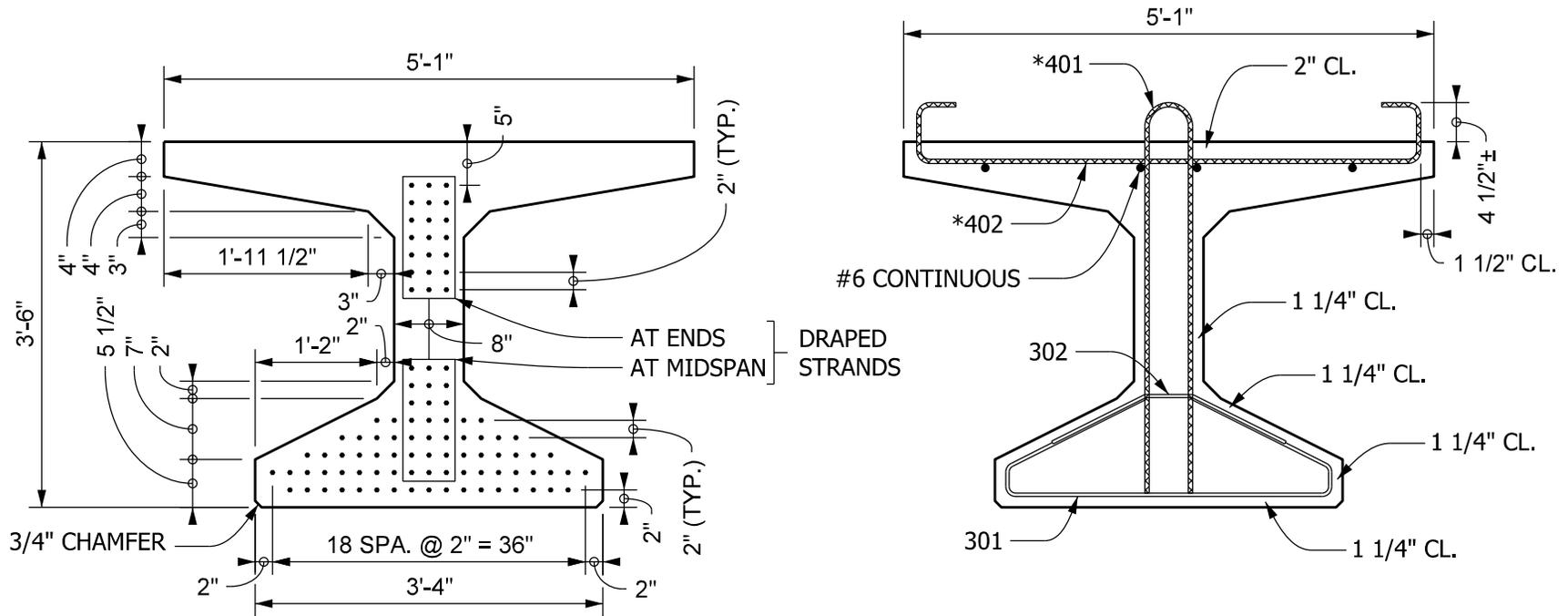
Figure 406-14S
 (Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



WIDE BULB-TEE BEAM TYPE BT 36 x 61 BAR BENDING DETAILS

Figure 406-14S
(Page 2 of 2)

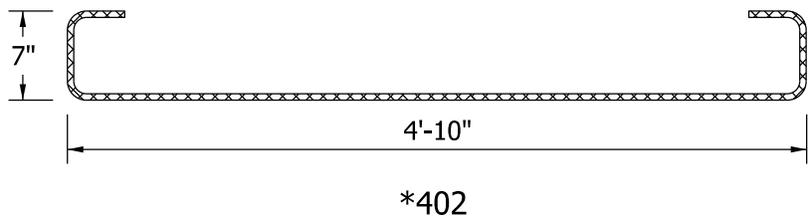
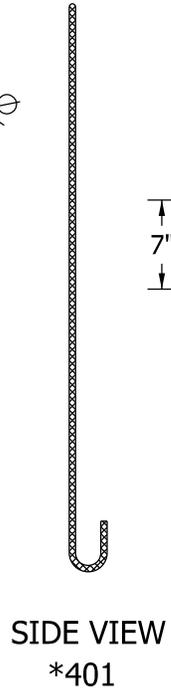
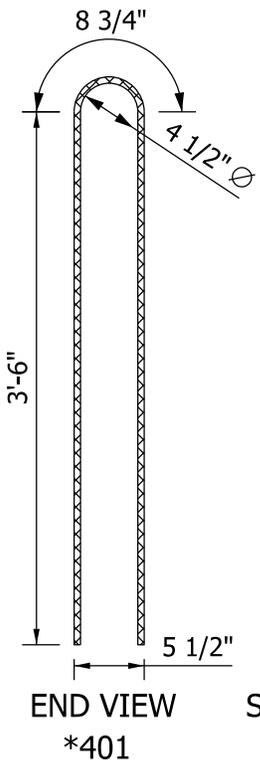
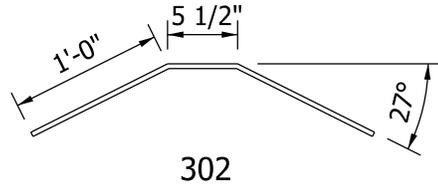
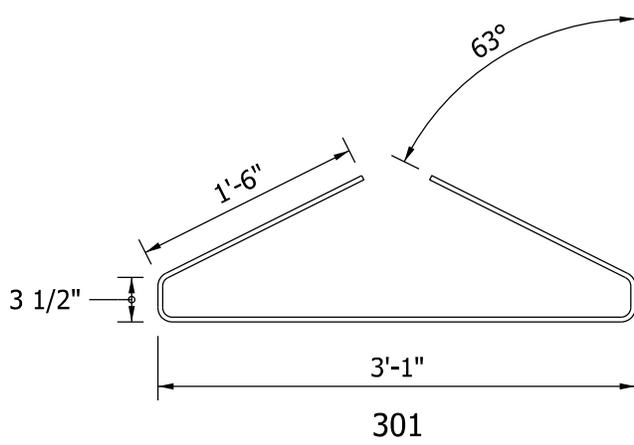


- NOTES:
1. *DENOTES EPOXY-COATED BARS.
 2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
 3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

**WIDE BULB-TEE BEAM TYPE BT 42 x 61
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

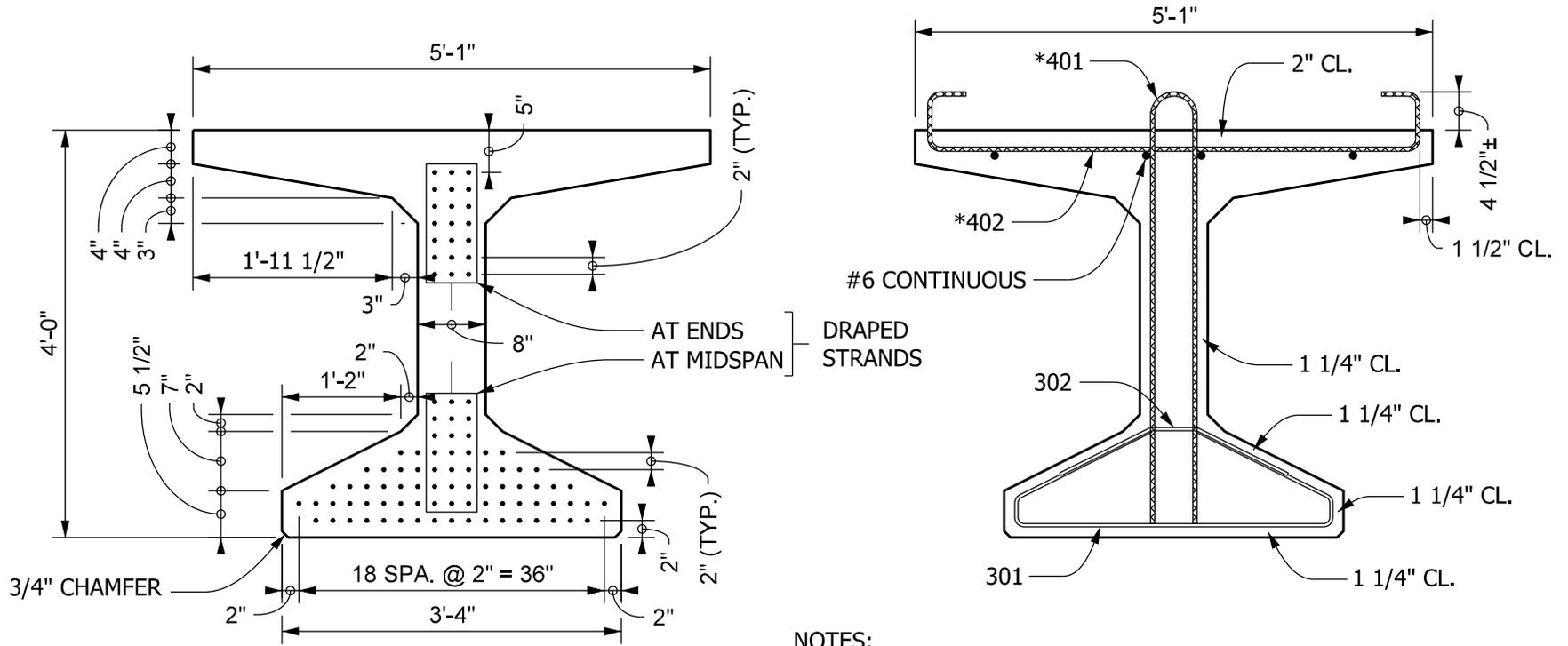
Figure 406-14T
(Page 1 of 2)

☒ * DENOTES EPOXY-COATED BARS



WIDE BULB-TEE BEAM TYPE BT 42 x 61 BAR BENDING DETAILS

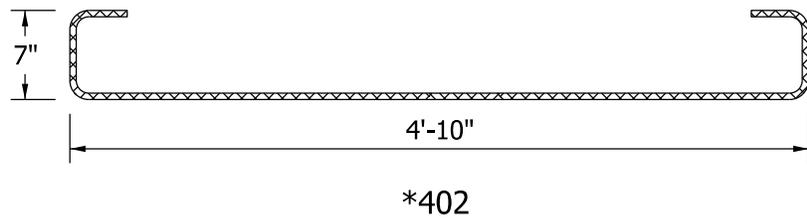
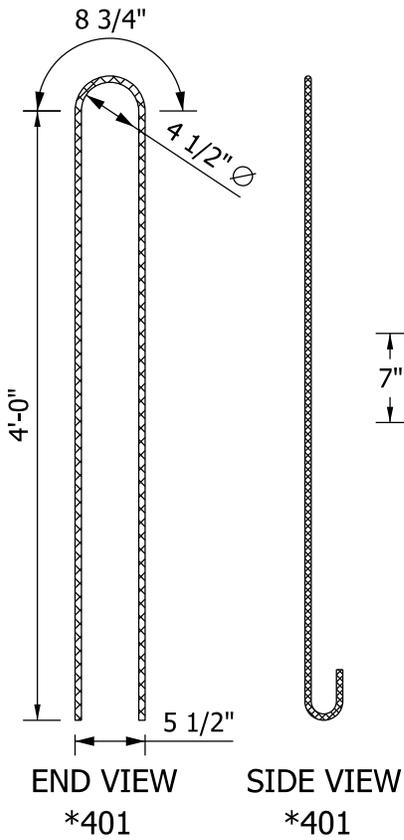
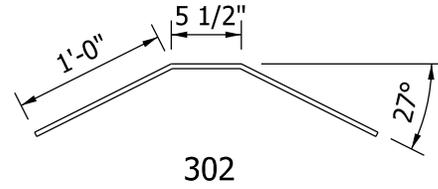
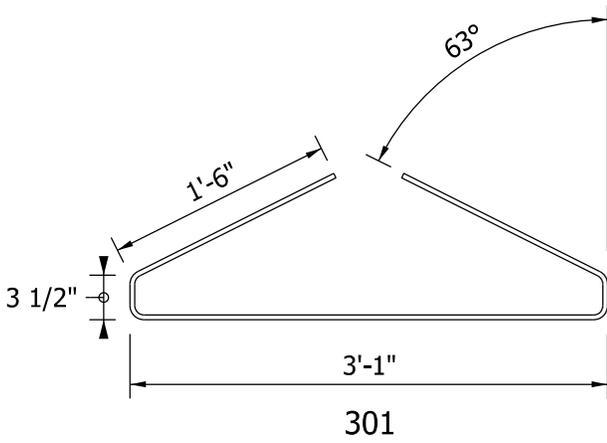
Figure 406-14T
(Page 2 of 2)



WIDE BULB-TEE BEAM TYPE BT 48 x 61
 SECTIONS SHOWING PRESTRESSING
 AND MILD REINFORCING STEEL

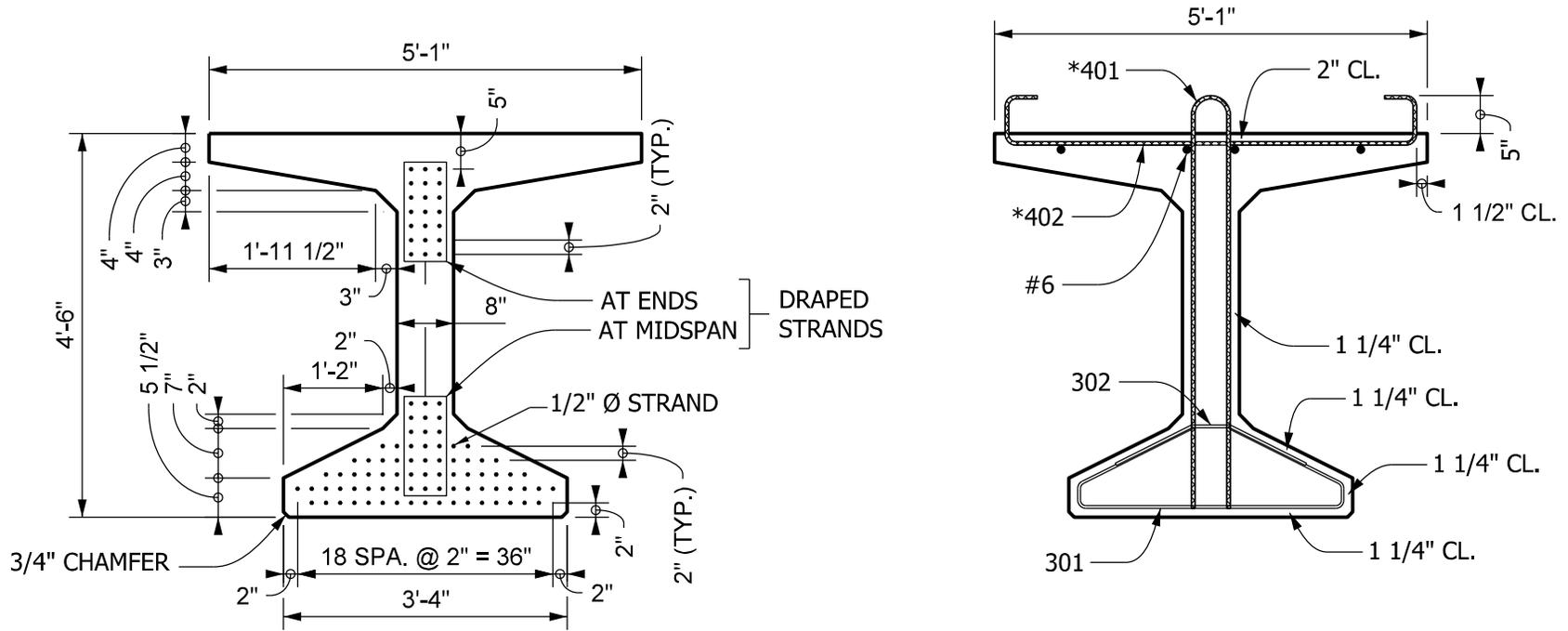
Figure 406-14U
 (Page 1 of 2)

 * DENOTES EPOXY-COATED BARS



WIDE BULB-TEE BEAM TYPE BT 48 x 61 BAR BENDING DETAILS

Figure 406-14U
(Page 2 of 2)



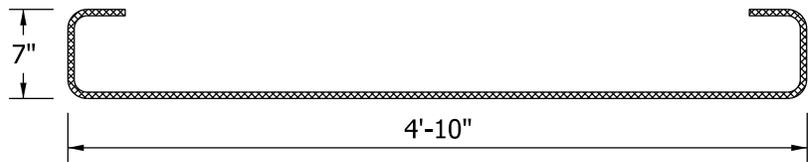
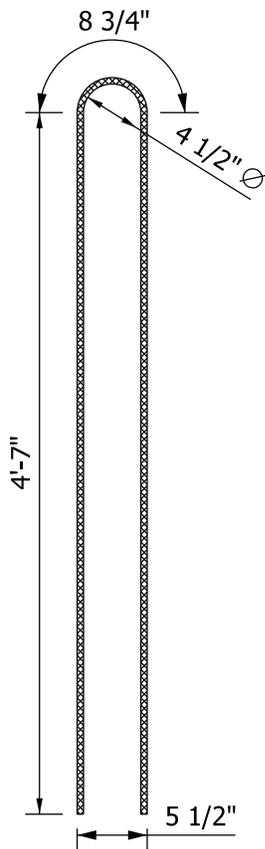
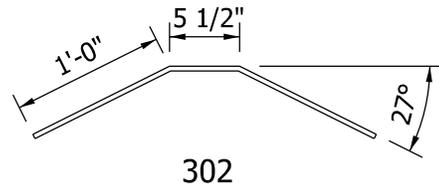
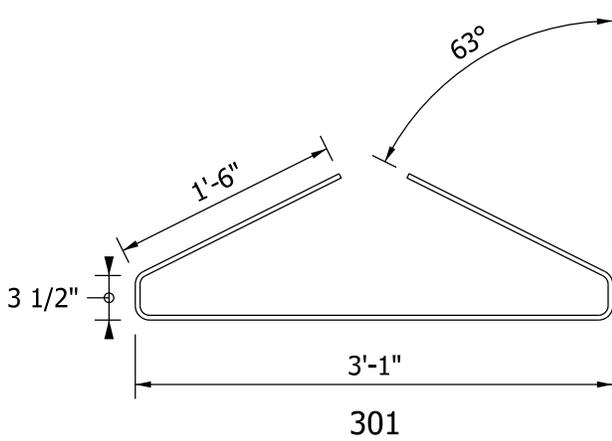
NOTES:

1. *DENOTES EPOXY-COATED BARS.
2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

**WIDE BULB-TEE BEAM TYPE BT 54 x 61
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

Figure 406-14V
(Page 1 of 2)

☒ * DENOTES EPOXY-COATED BARS

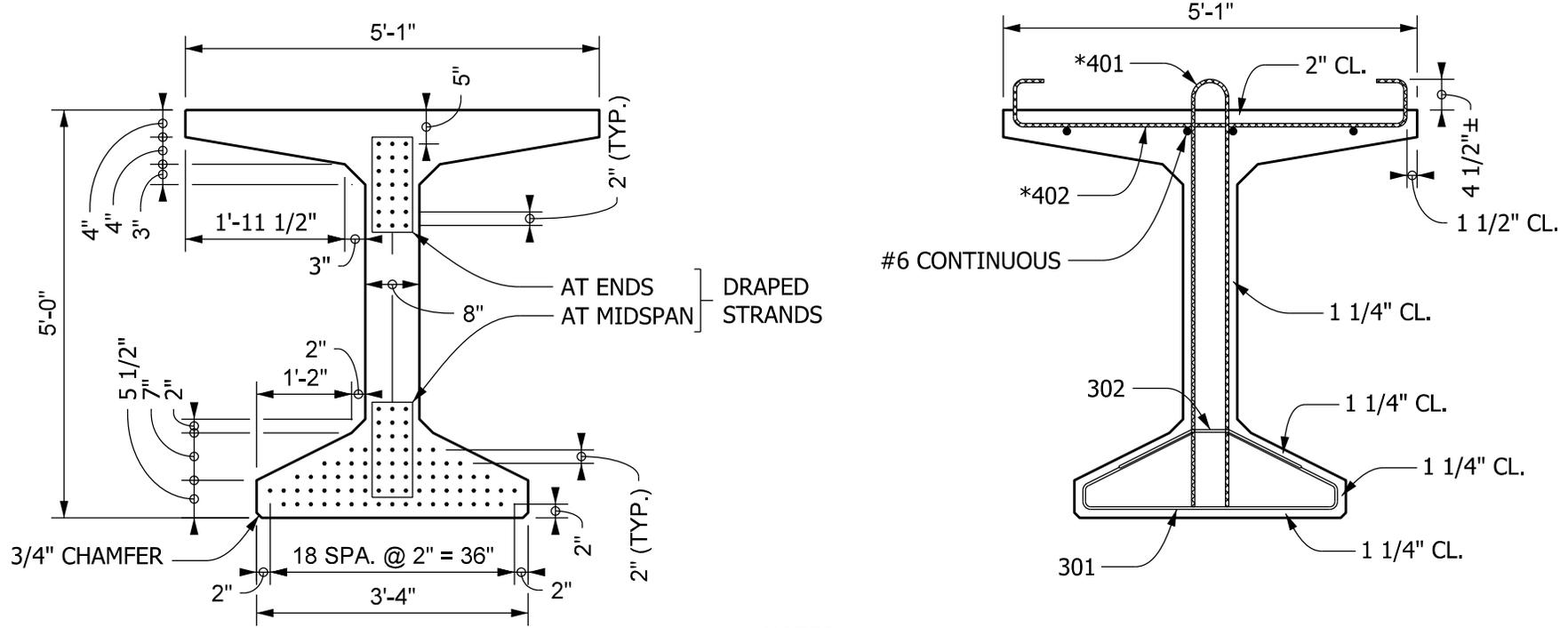


END VIEW
*401

SIDE VIEW
*401

WIDE BULB-TEE BEAM TYPE BT 54 x 61 BAR BENDING DETAILS

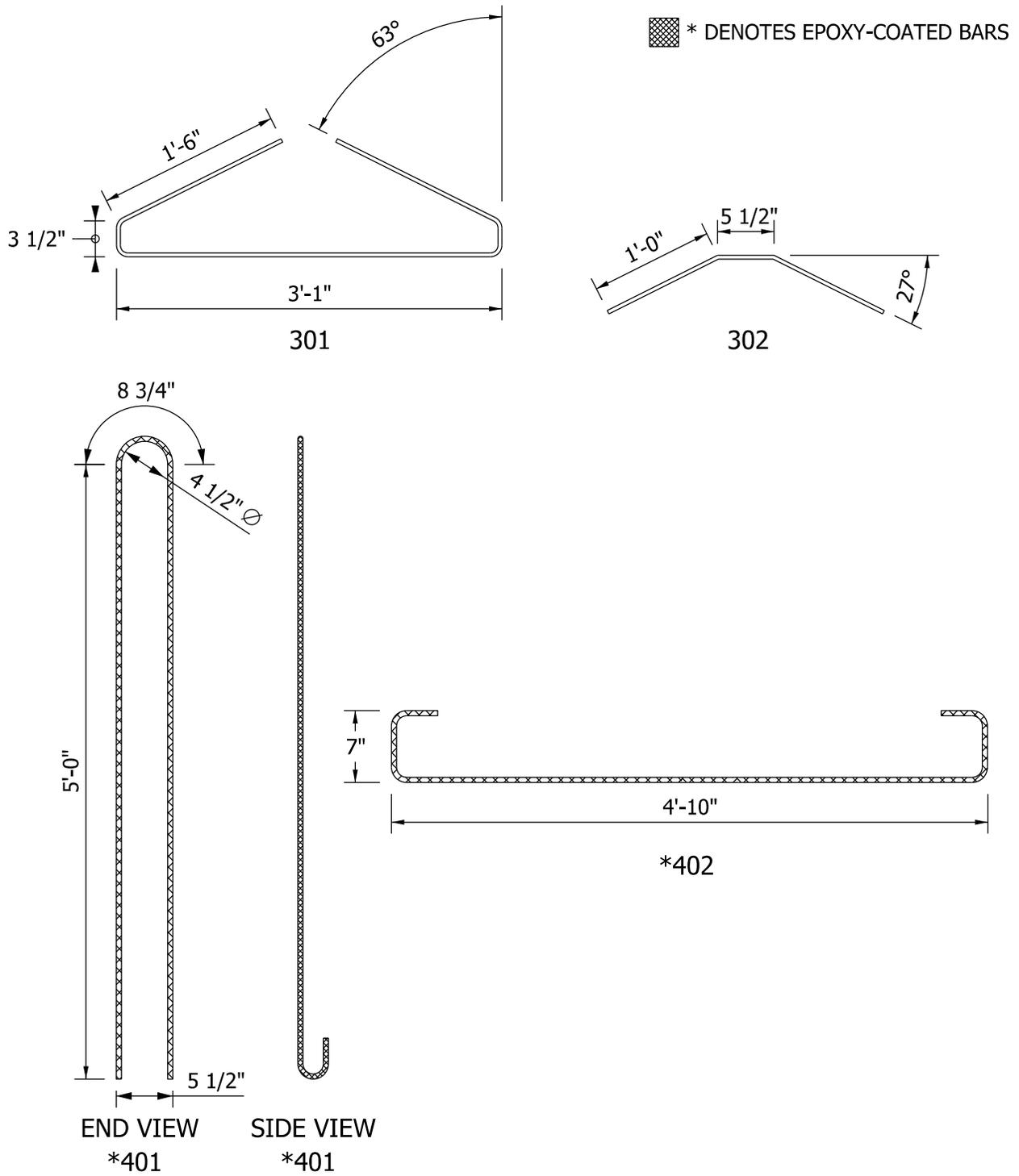
Figure 406-14V
(Page 2 of 2)



- NOTES:
1. *DENOTES EPOXY-COATED BARS.
 2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
 3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

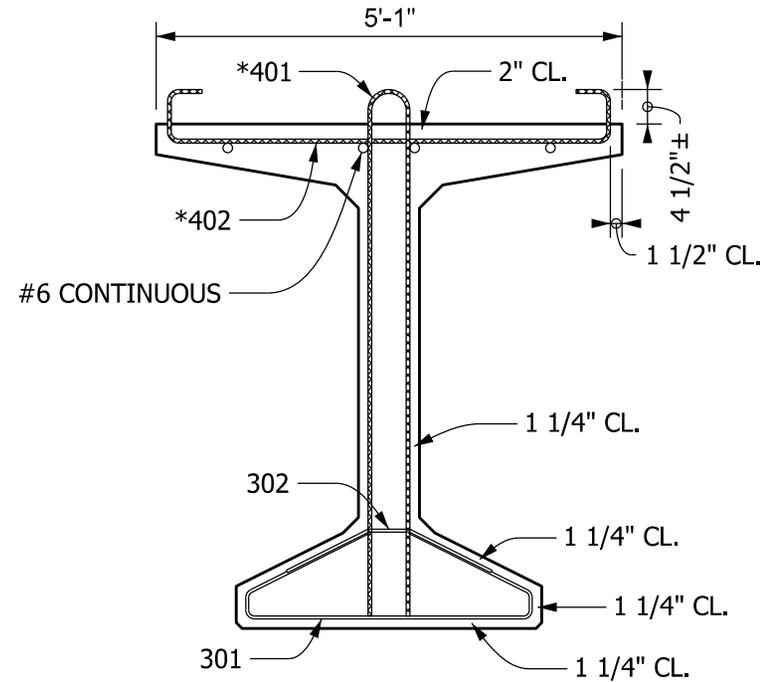
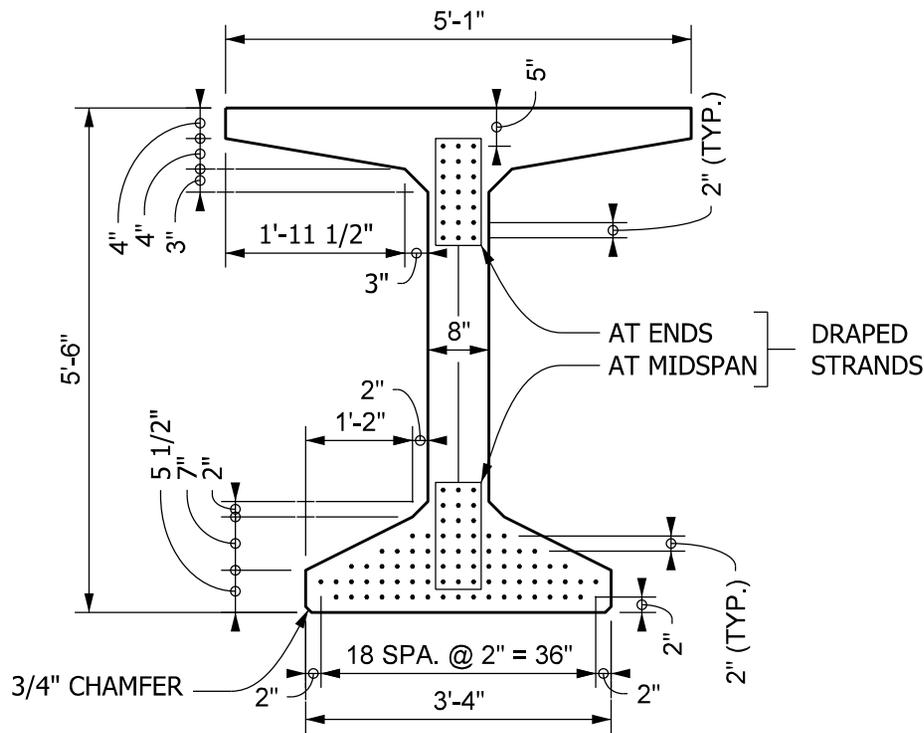
**WIDE BULB-TEE BEAM TYPE BT 60 x 61
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL**

Figure 406-14W
(Page 1 of 2)



WIDE BULB-TEE BEAM TYPE BT 60 x 61
BAR BENDING DETAILS

Figure 406-14W
(Page 2 of 2)

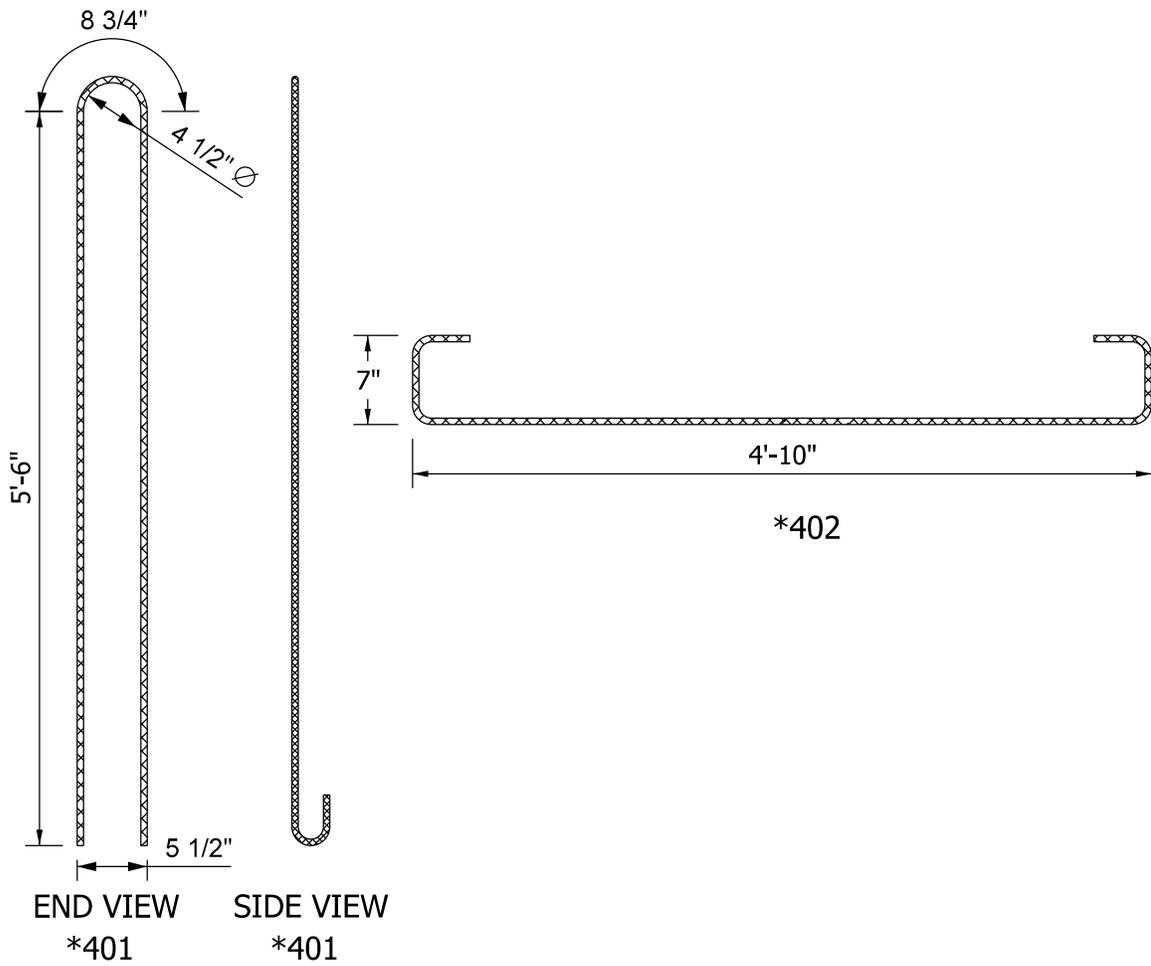
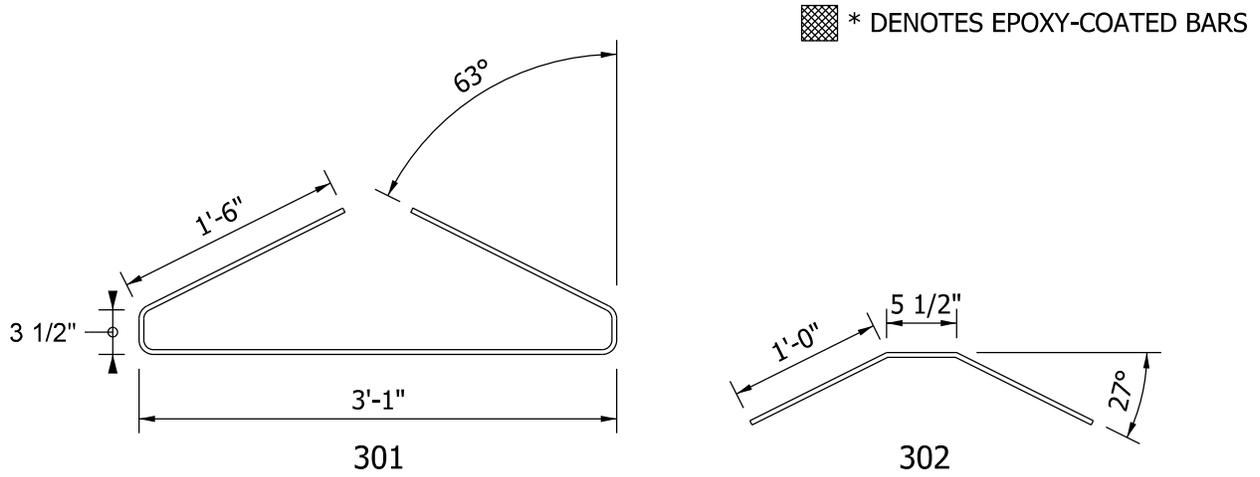


NOTES:

1. *DENOTES EPOXY-COATED BARS.
2. LOCATE HOLDDOWNS 5'-0" EACH SIDE OF CENTER LINE OF BEAM.
3. BARS 301 AND 302 COMBINE TO FORM ONE STIRRUP.

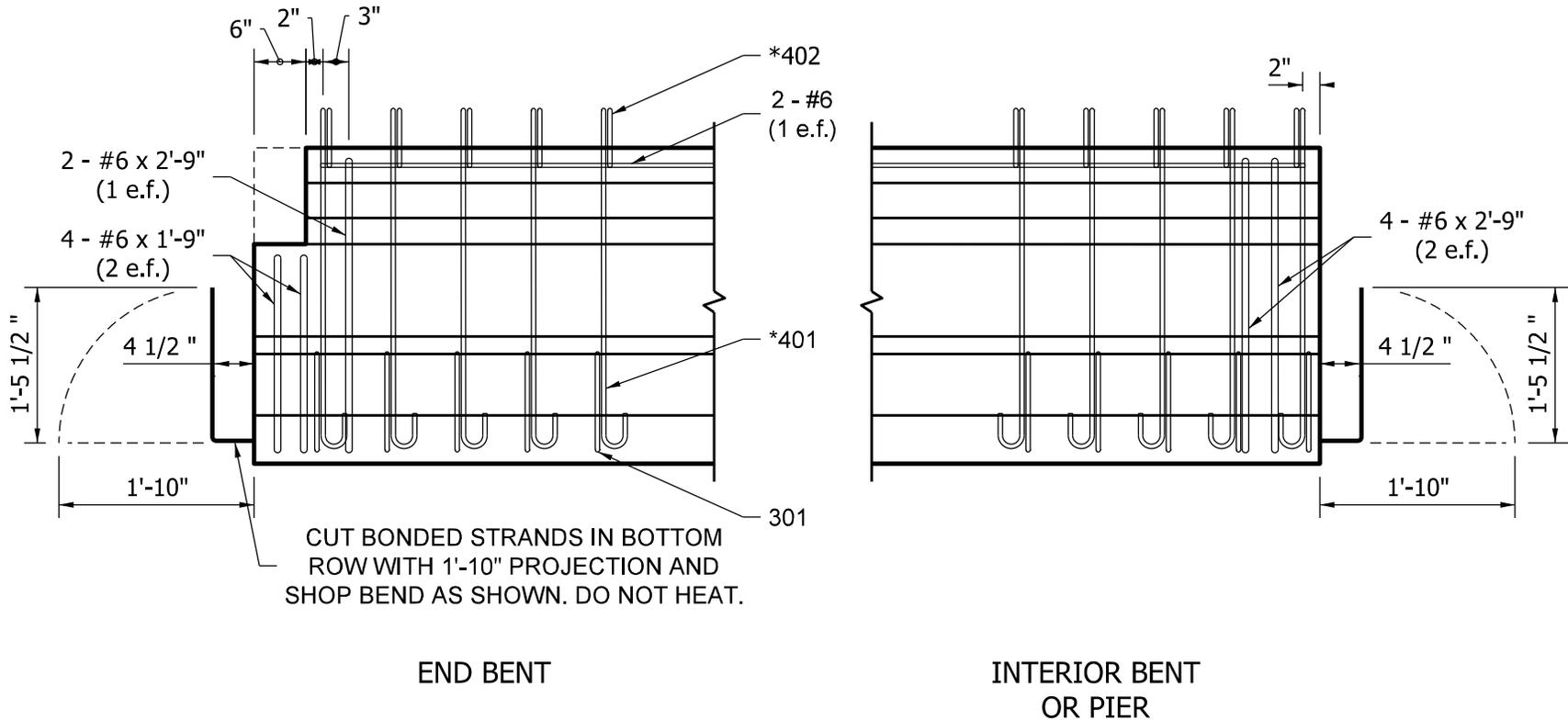
WIDE BULB-TEE BEAM TYPE BT 66 x 61
SECTIONS SHOWING PRESTRESSING
AND MILD REINFORCING STEEL

Figure 406-14X
(Page 1 of 2)



WIDE BULB-TEE BEAM TYPE BT 66 x 61
BAR BENDING DETAILS

Figure 406-14X
(Page 2 of 2)

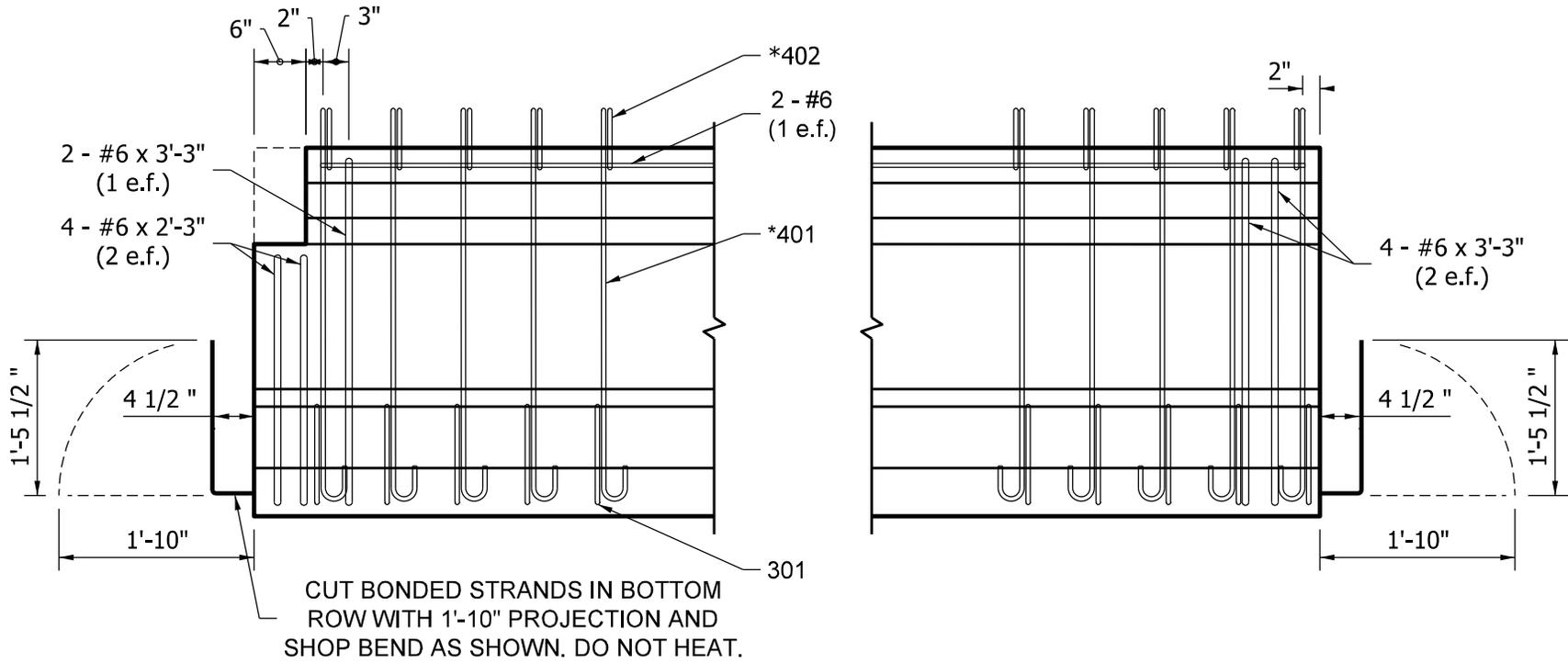


NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

BULB - TEE BEAM (36 DEPTH) ELEVATIONS SHOWING END REINFORCEMENT

Figure 406-14Y
(Page 1 of 9)



END BENT

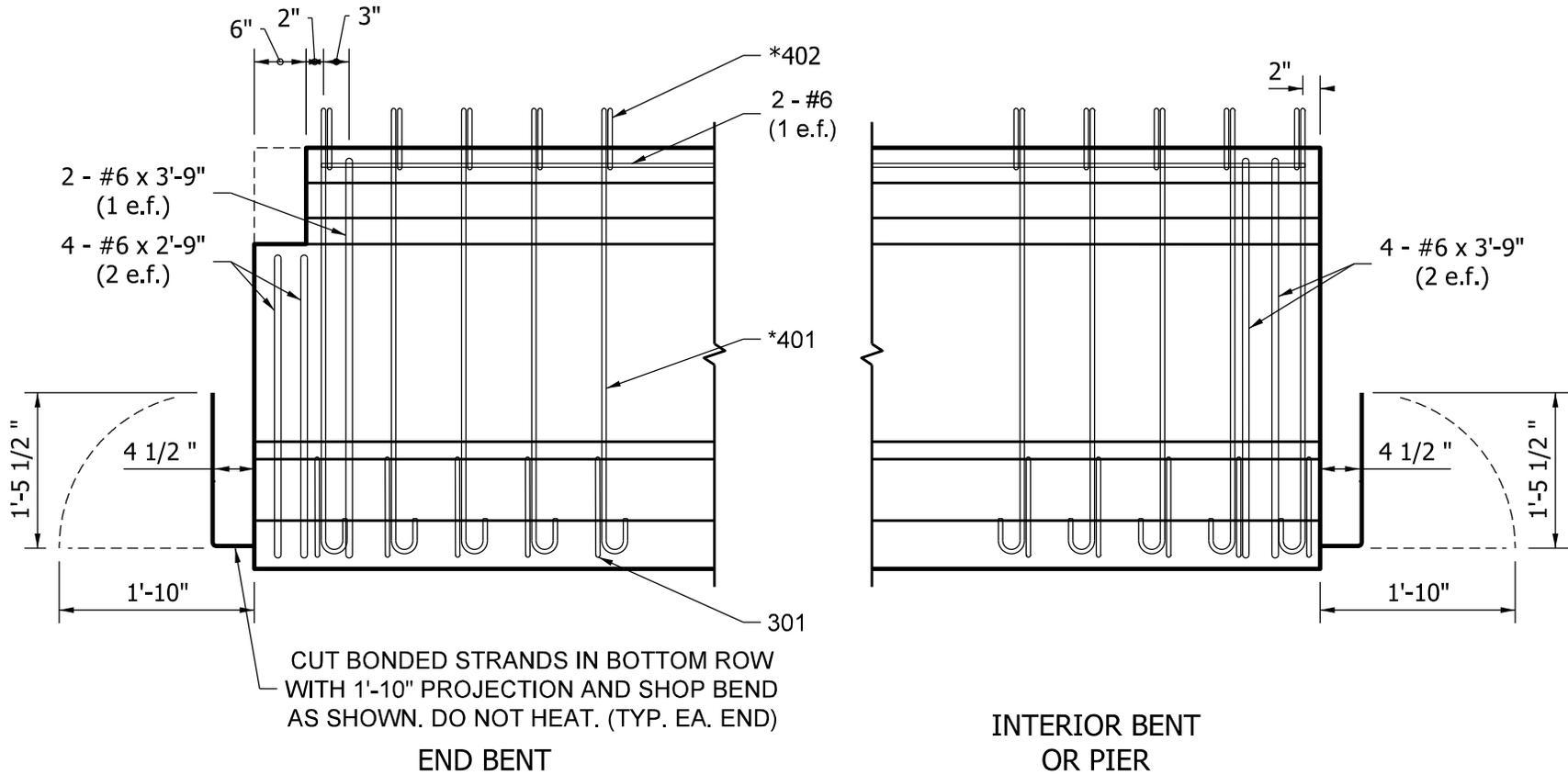
INTERIOR BENT OR PIER

NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

BULB - TEE BEAM (42 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT

Figure 406-14Y
(Page 2 of 9)

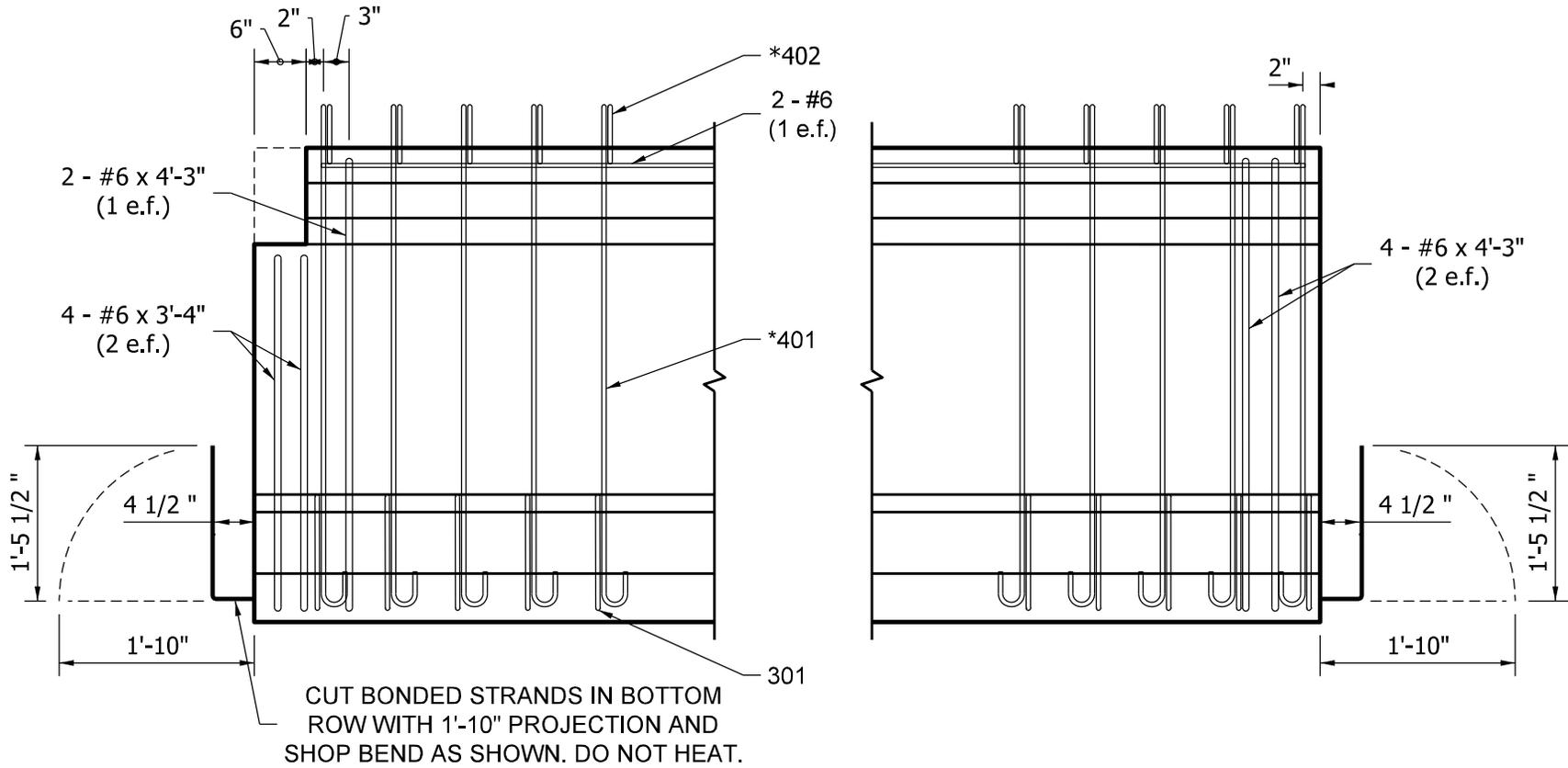


NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

**BULB - TEE BEAM (48 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 3 of 9)

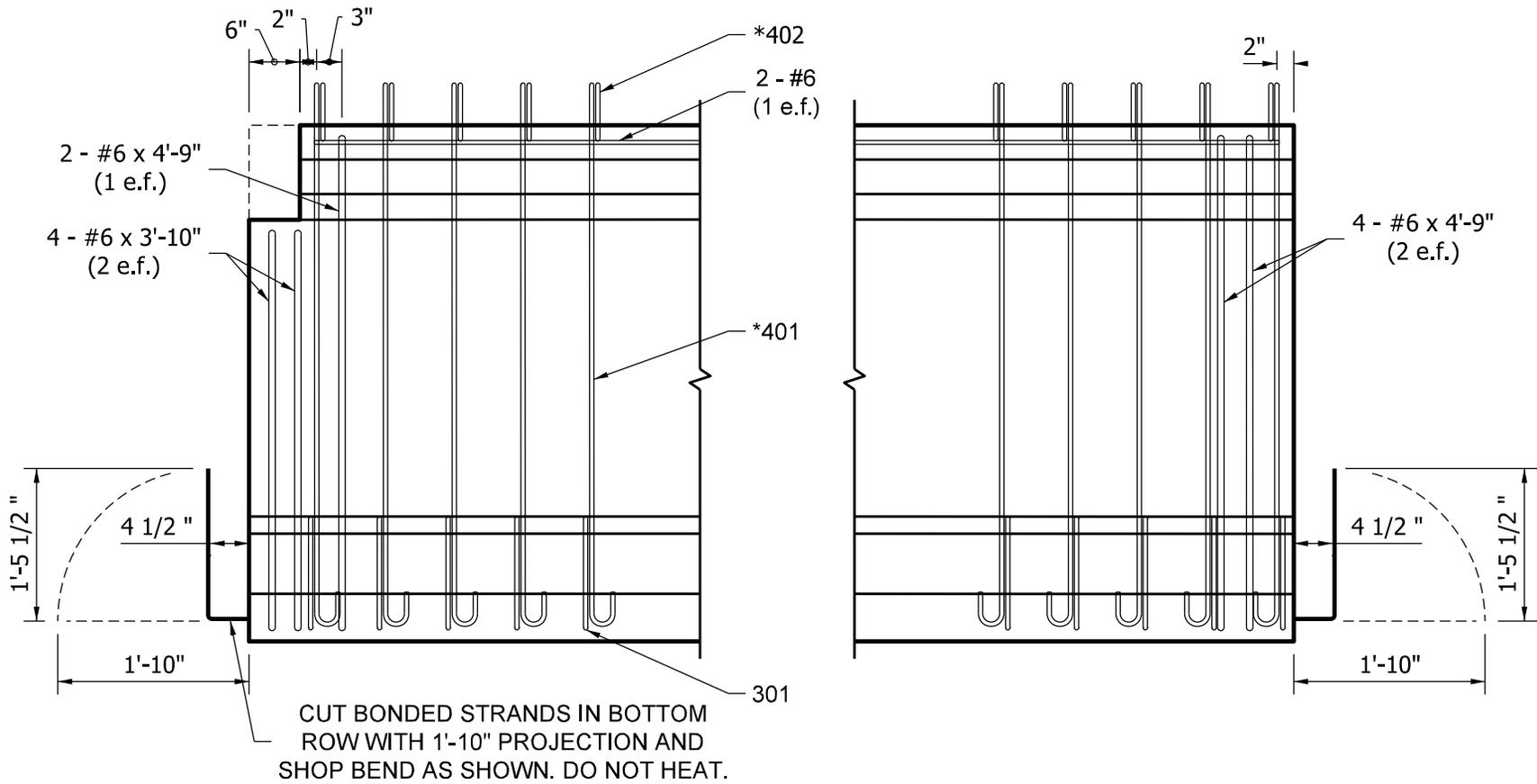


NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

**BULB - TEE BEAM (54 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 4 of 9)

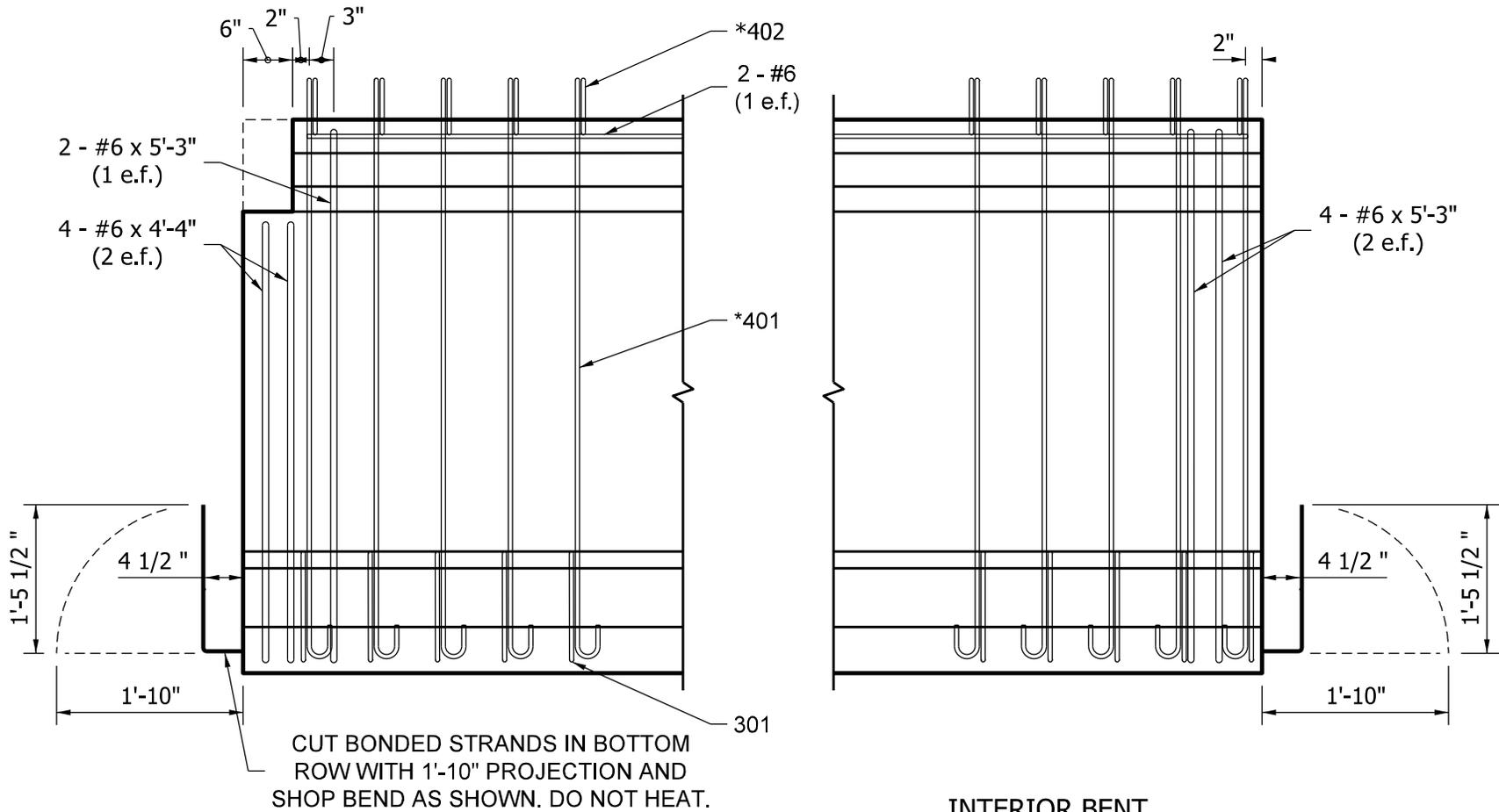


NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

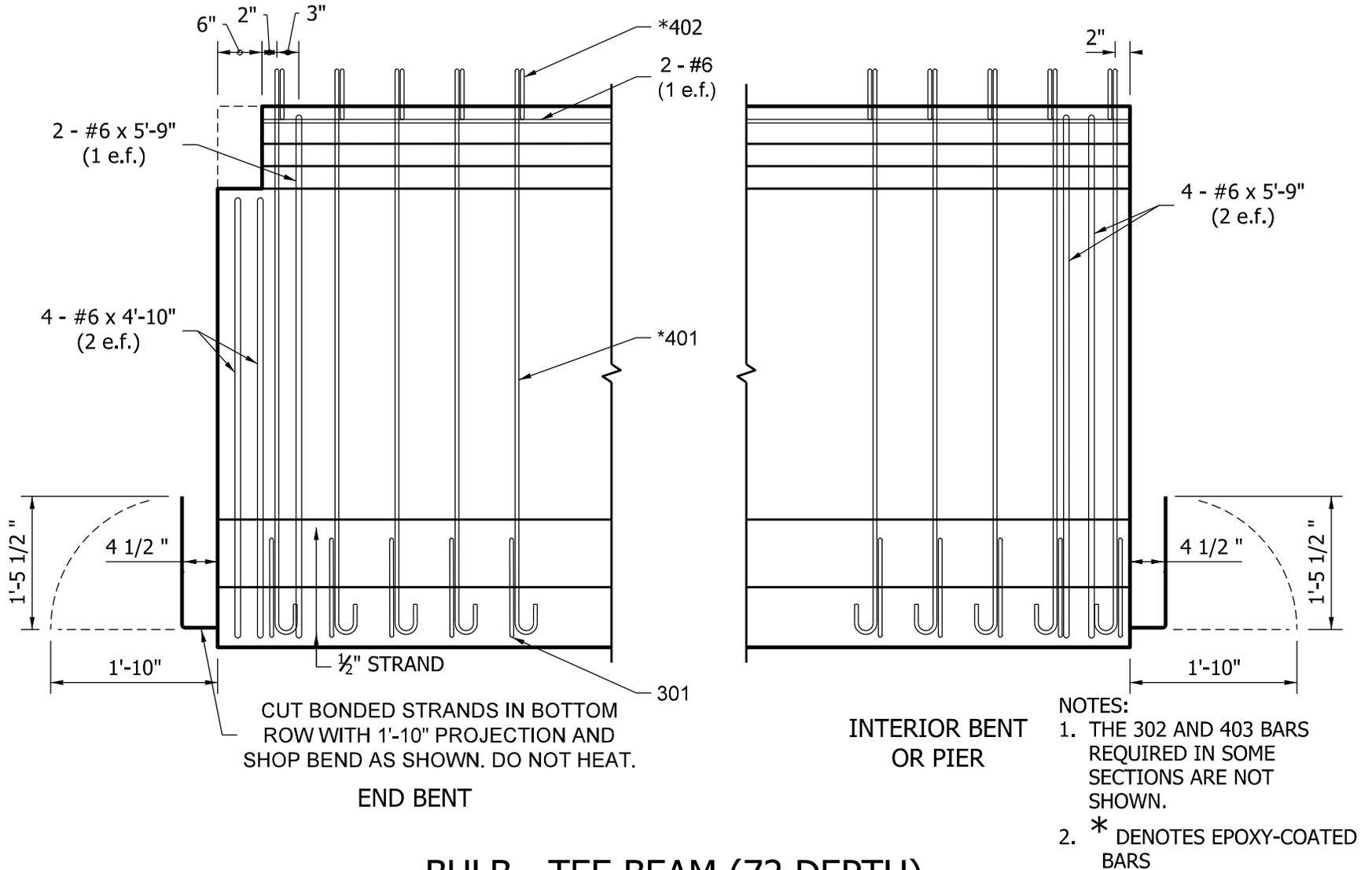
**BULB - TEE BEAM (60 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 5 of 9)



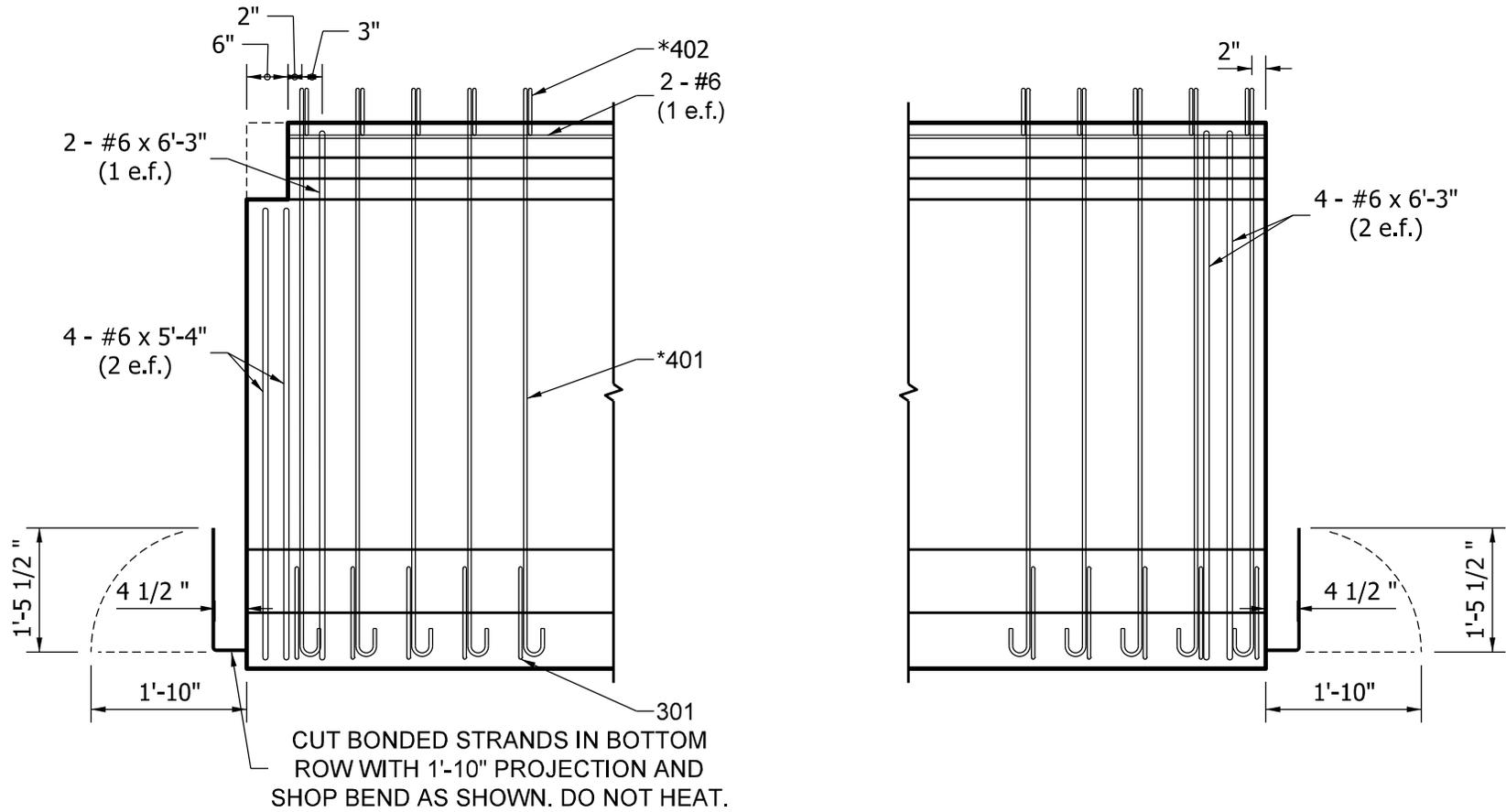
**BULB - TEE BEAM (66 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 6 of 9)



**BULB - TEE BEAM (72 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 7 of 9)

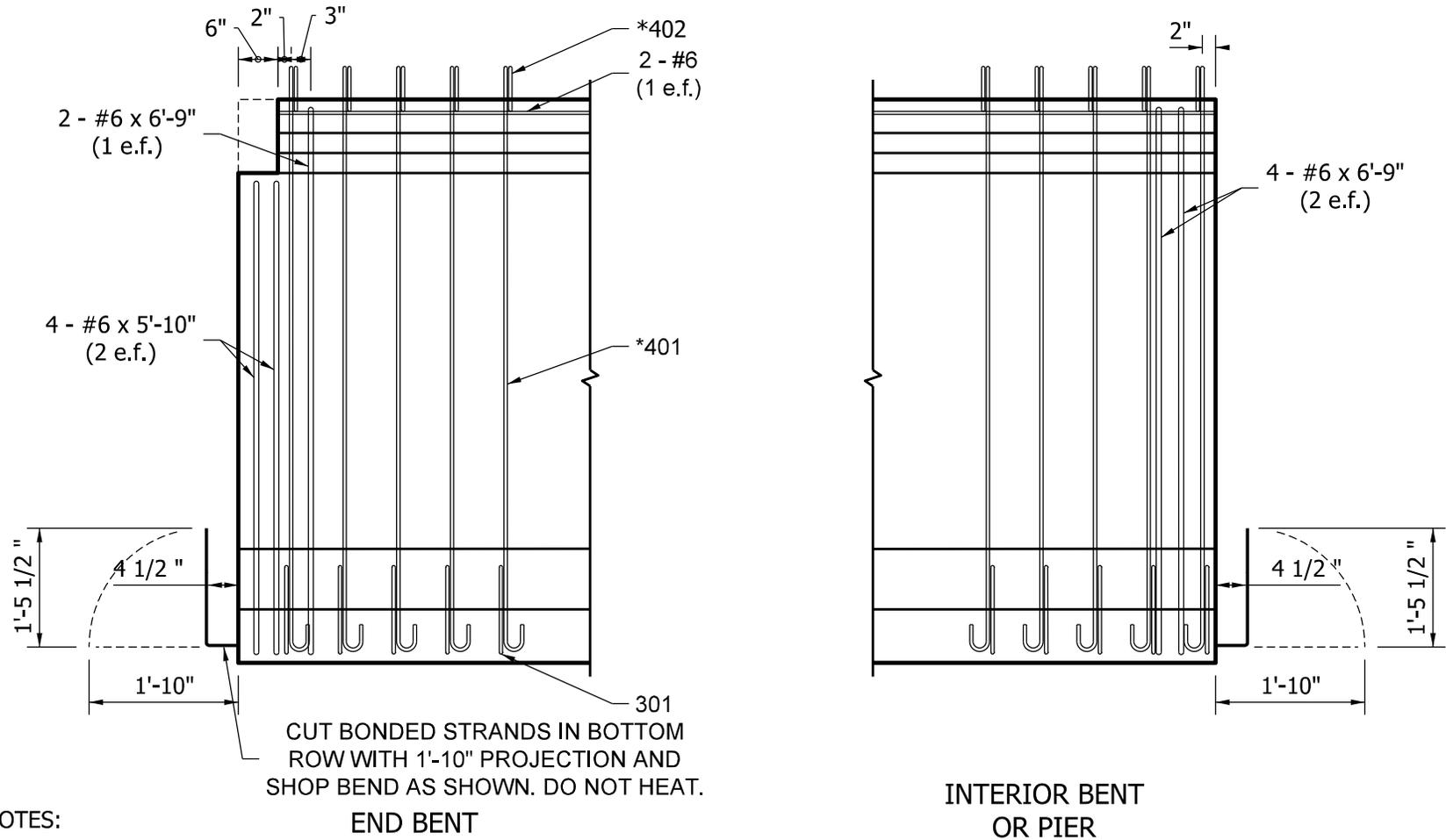


NOTES:

1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

**BULB - TEE BEAM (78 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 8 of 9)



NOTES:

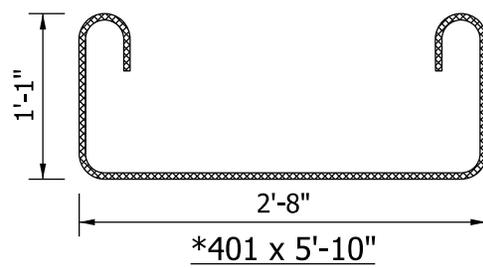
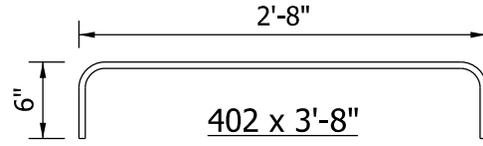
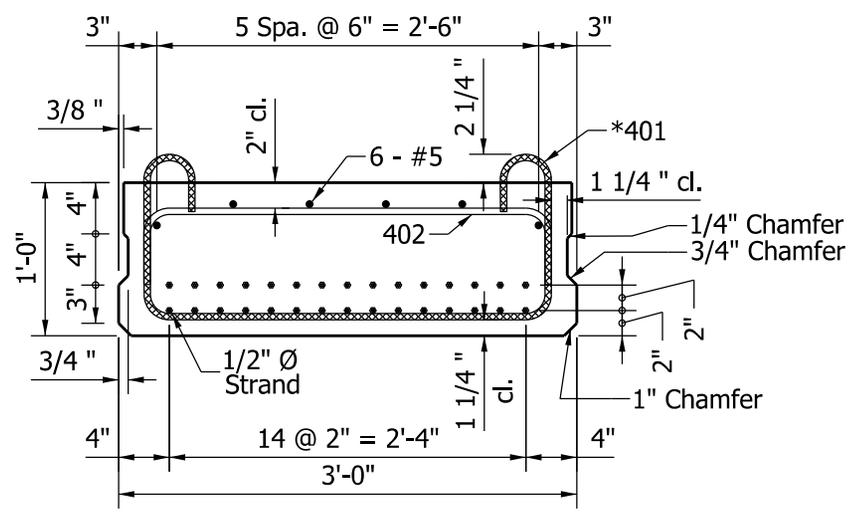
1. THE 302 AND 403 BARS REQUIRED IN SOME SECTIONS ARE NOT SHOWN.
2. * DENOTES EPOXY-COATED BARS

**BULB - TEE BEAM (84 DEPTH)
ELEVATIONS SHOWING END REINFORCEMENT**

Figure 406-14Y
(Page 9 of 9)

BEAM PROPERTIES	
A_B	= 423 in ²
I_B	= 5,124 in ⁴
S_{TB}	= 850 in ³
S_{BB}	= 858 in ³
Y_{TB}	= 6.03 in
Y_{BB}	= 5.97 in
Wt.	= 441 lbs/ft

NOTES:
 1.  *DENOTES EPOXY-COATED BAR

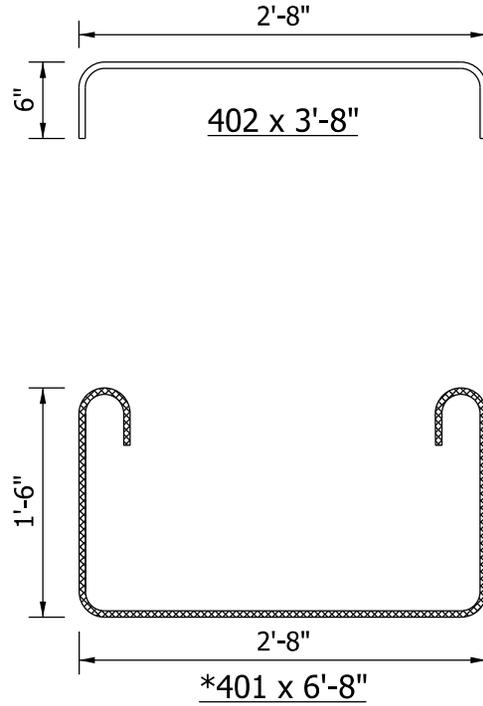
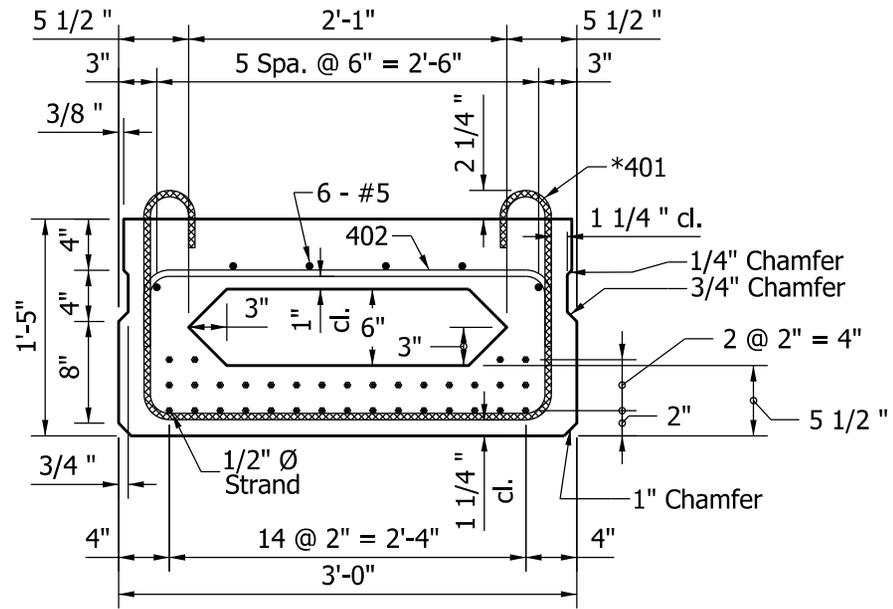


BOX BEAM
 TYPE CB 12 x 36

Figure 406-15A

BEAM PROPERTIES	
A_B	= 471 in ²
I_B	= 14,169 in ⁴
S_{TB}	= 1,653 in ³
S_{BB}	= 1,681 in ³
Y_{TB}	= 8.57 in
Y_{BB}	= 8.43 in
Wt.	= 491 lbs/ft

NOTES:
 1.  *DENOTES EPOXY-COATED BAR



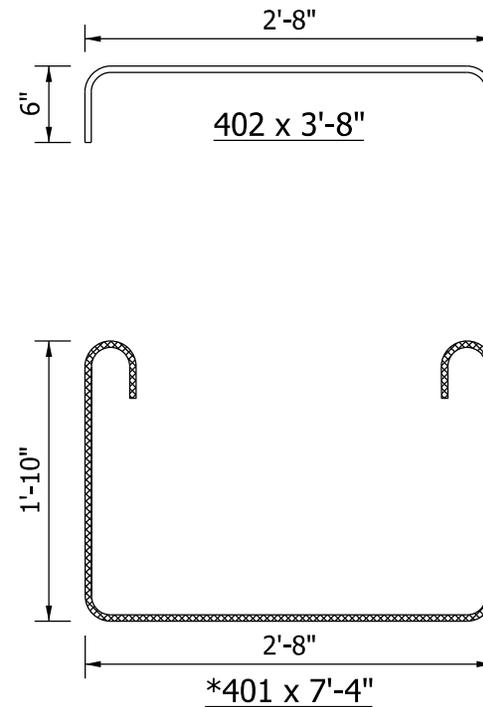
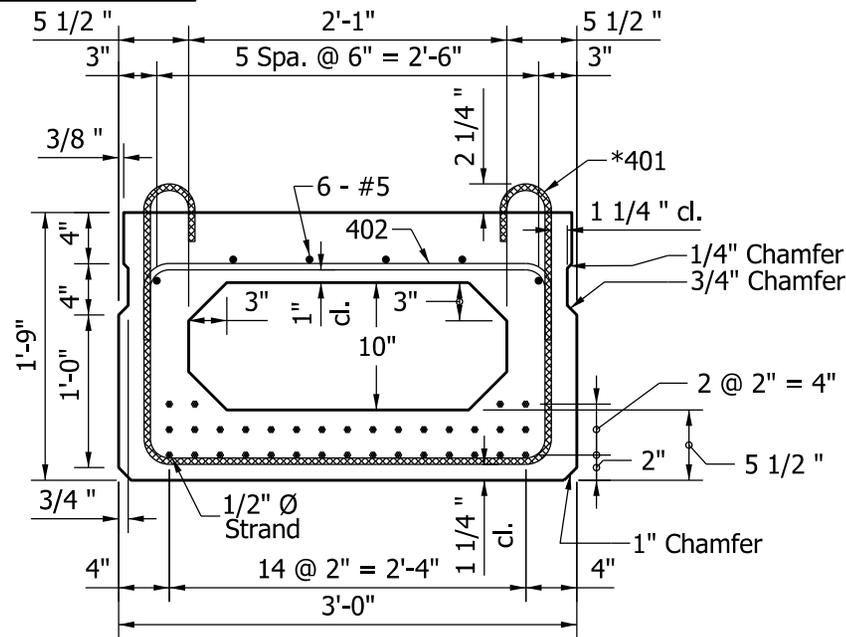
**BOX BEAM
 TYPE CB 17 x 36**

Figure 406-15B

BEAM PROPERTIES	
A_B	= 515 in ²
I_B	= 27,619 in ⁴
S_{TB}	= 2,417 in ³
S_{BB}	= 2,463 in ³
Y_{TB}	= 10.60 in
Y_{BB}	= 10.40 in
Wt.	= 536 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR

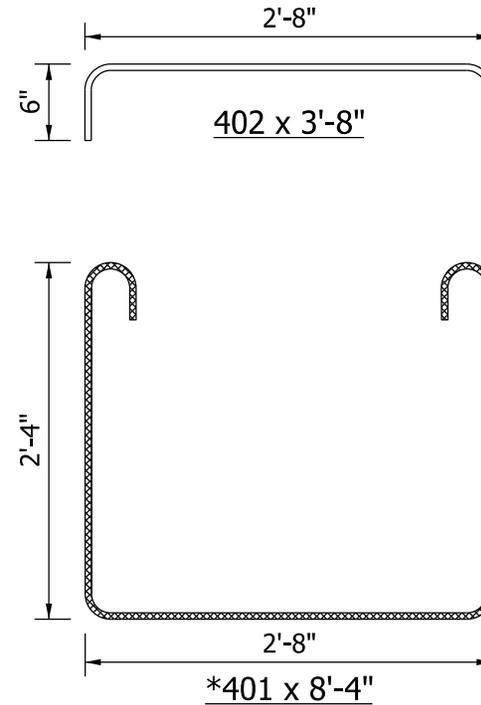
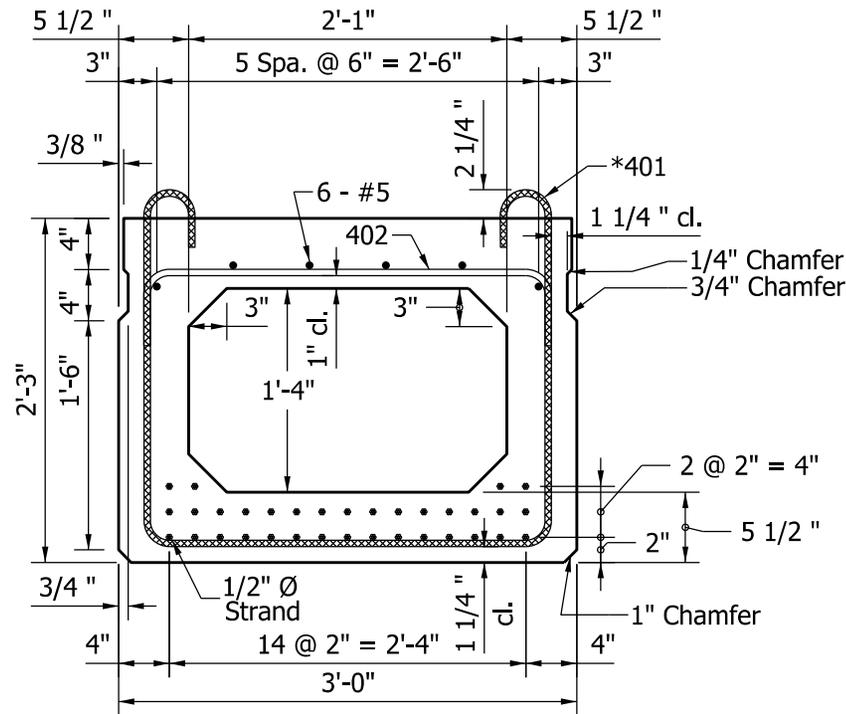


BOX BEAM
TYPE CB 21 x 36

Figure 406-15C

BEAM PROPERTIES	
A_B	= 581 in ²
I_B	= 50,627 in ⁴
STB	= 3,712 in ³
SBB	= 3,789 in ³
Y_{TB}	= 13.64 in
Y_{BB}	= 13.36 in
Wt.	= 605 lbs/ft

NOTES:
 1.  *DENOTES EPOXY-COATED BAR



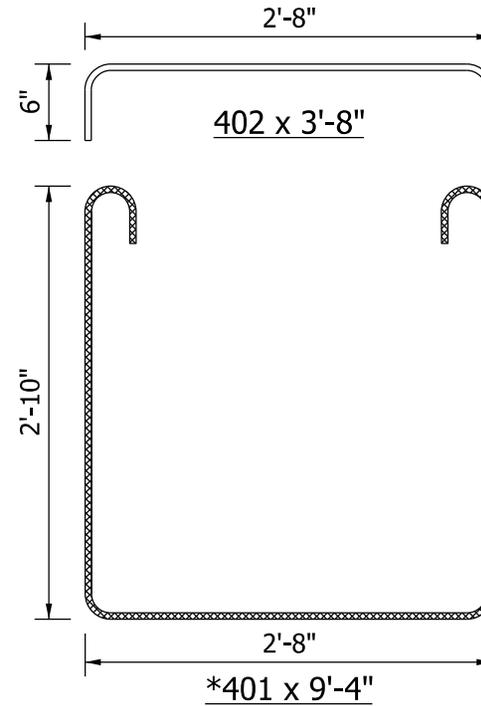
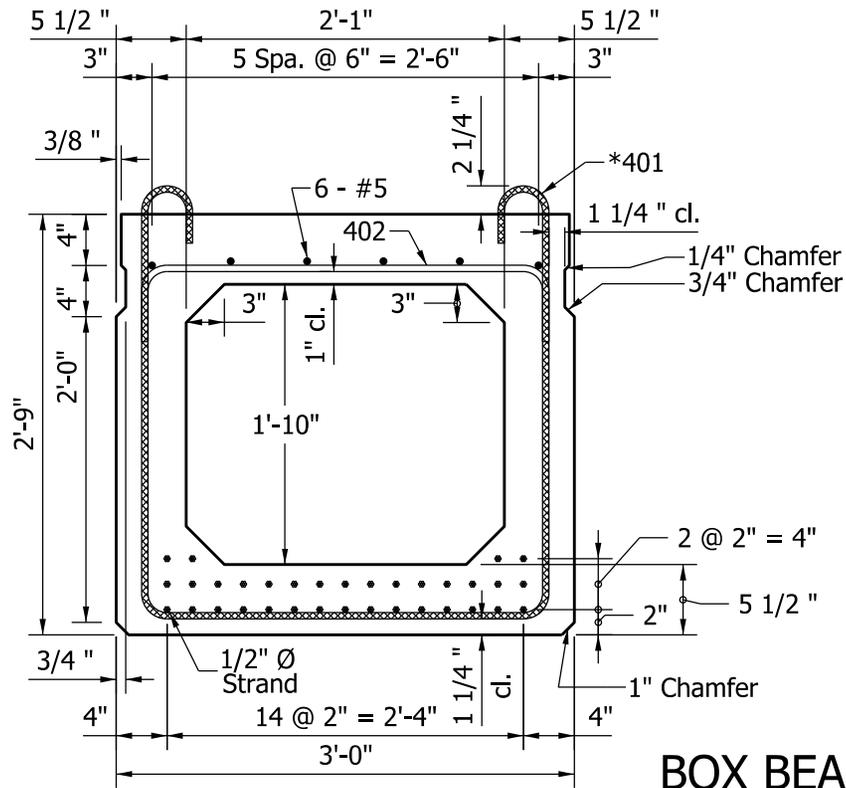
BOX BEAM
 TYPE CB 27 x 36

Figure 406-15D

BEAM PROPERTIES	
A_B	= 647 in ²
I_B	= 86,092 in ⁴
S_{TB}	= 5,168 in ³
S_{BB}	= 5,269 in ³
Y_{TB}	= 16.66 in
Y_{BB}	= 16.34 in
Wt.	= 674 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR



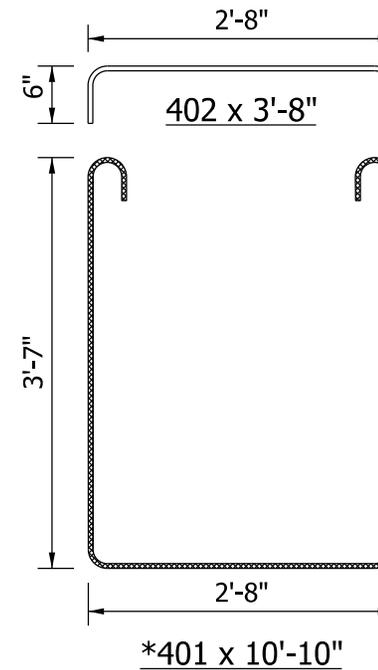
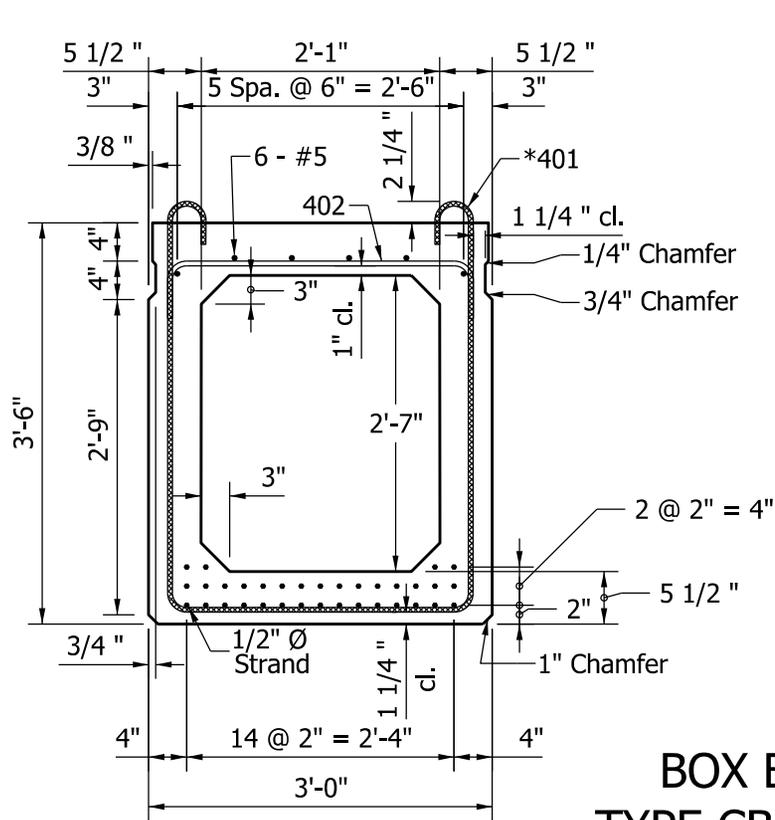
**BOX BEAM
TYPE CB 33 x 36**

Figure 406-15E

BEAM PROPERTIES	
A_B	= 746 in ²
I_B	= 161,496 in ⁴
STB	= 7,618 in ³
SBB	= 7,764 in ³
Y_{TB}	= 21.20 in
Y_{BB}	= 20.80 in
Wt.	= 777 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR



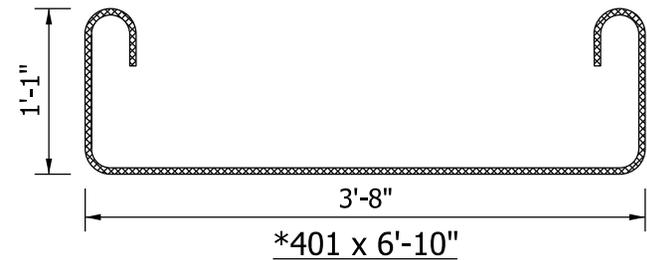
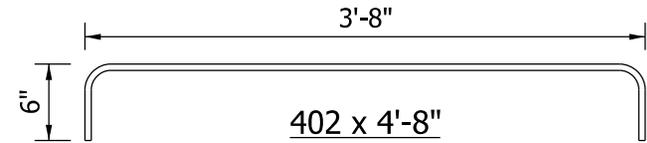
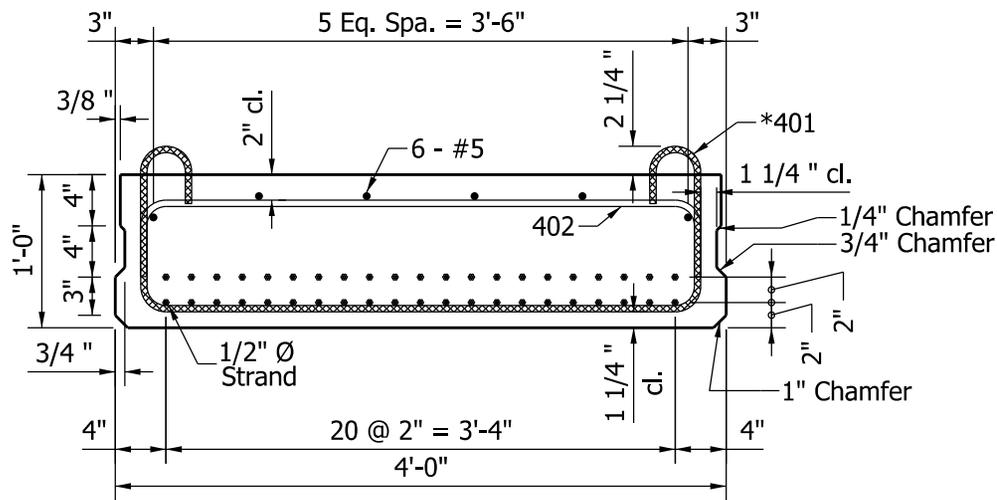
**BOX BEAM
TYPE CB 42 x 36**

Figure 406-15F

BEAM PROPERTIES	
A_B	= 567 in ²
I_B	= 6,852 in ⁴
STB	= 1,138 in ³
SBB	= 1,146 in ³
Y_{TB}	= 6.02 in
Y_{BB}	= 5.98 in
Wt.	= 591 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR

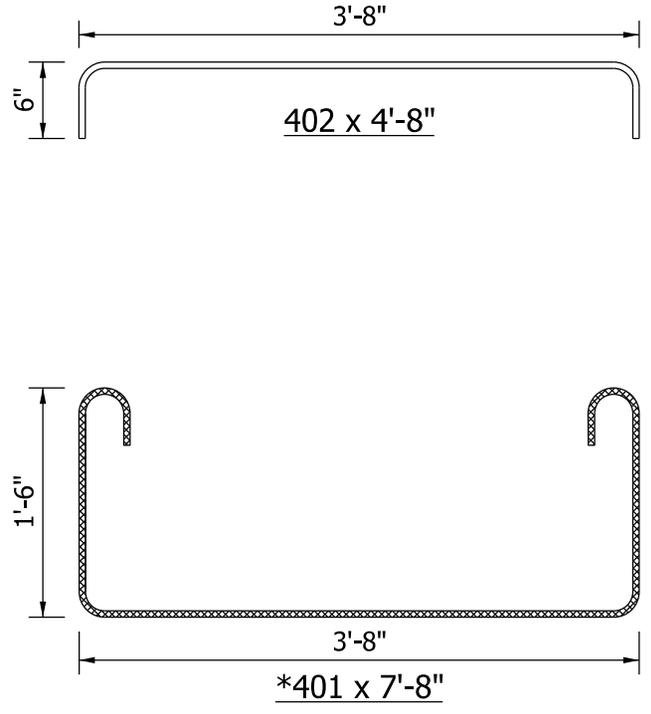
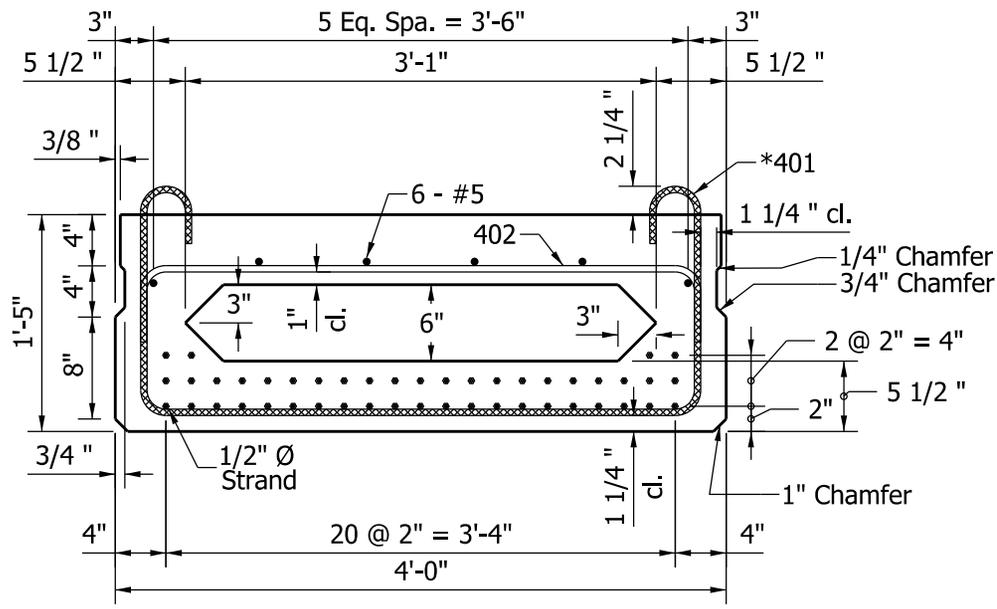


BOX BEAM
TYPE CB 12 x 48

Figure 406-15G

BEAM PROPERTIES	
A_B	= 603 in ²
I_B	= 18,866 in ⁴
STB	= 2,204 in ³
SBB	= 2,235 in ³
Y_{TB}	= 8.56 in
Y_{BB}	= 8.44 in
Wt.	= 628 lbs/ft

NOTES:
 1.  *DENOTES EPOXY-COATED BAR



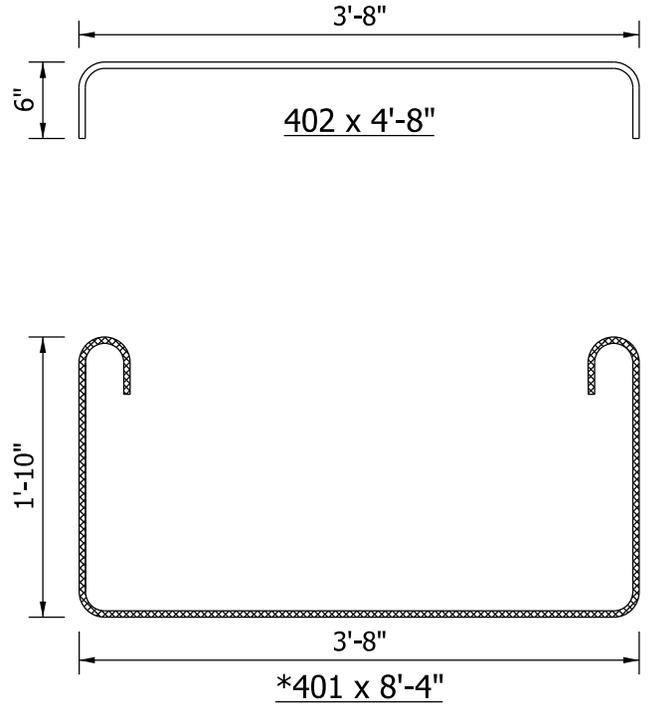
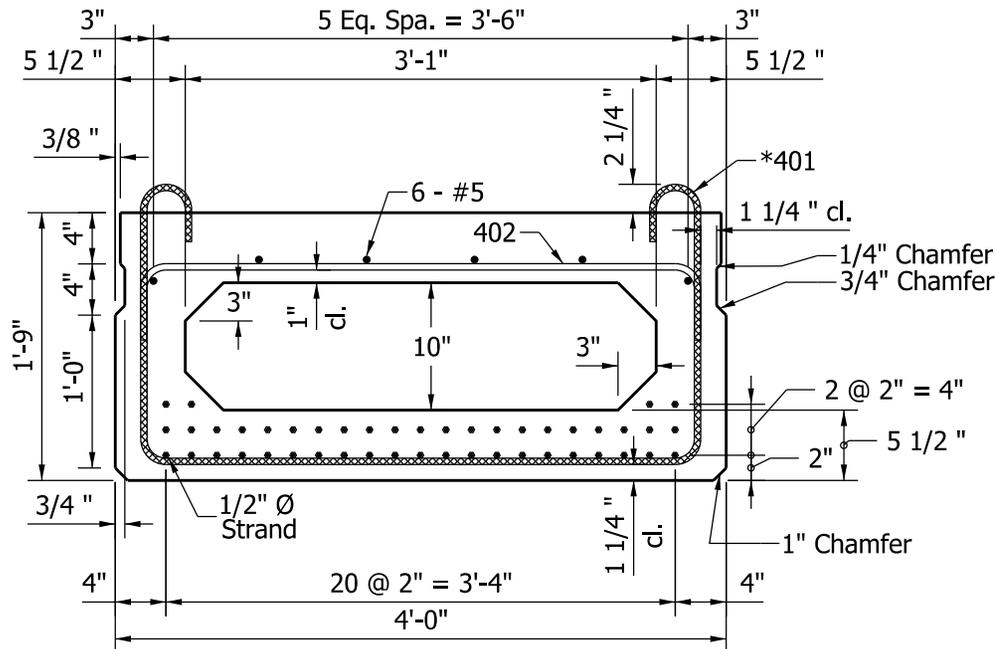
BOX BEAM
 TYPE CB 17 x 48

Figure 406-15H

BEAM PROPERTIES	
A_B	= 647 in ²
I_B	= 33,881 in ⁴
STB	= 3,202 in ³
SBB	= 3,252 in ³
Y_{TB}	= 10.58 in
Y_{BB}	= 10.42 in
Wt.	= 674 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR

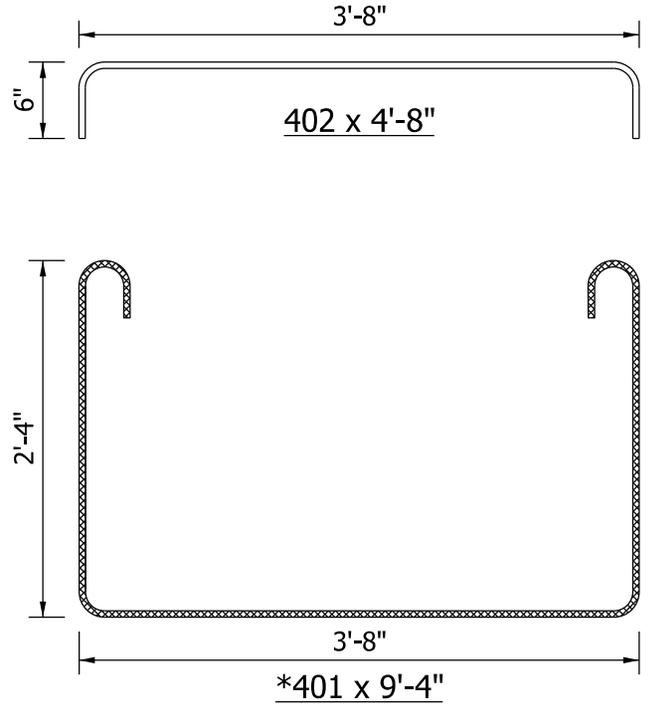
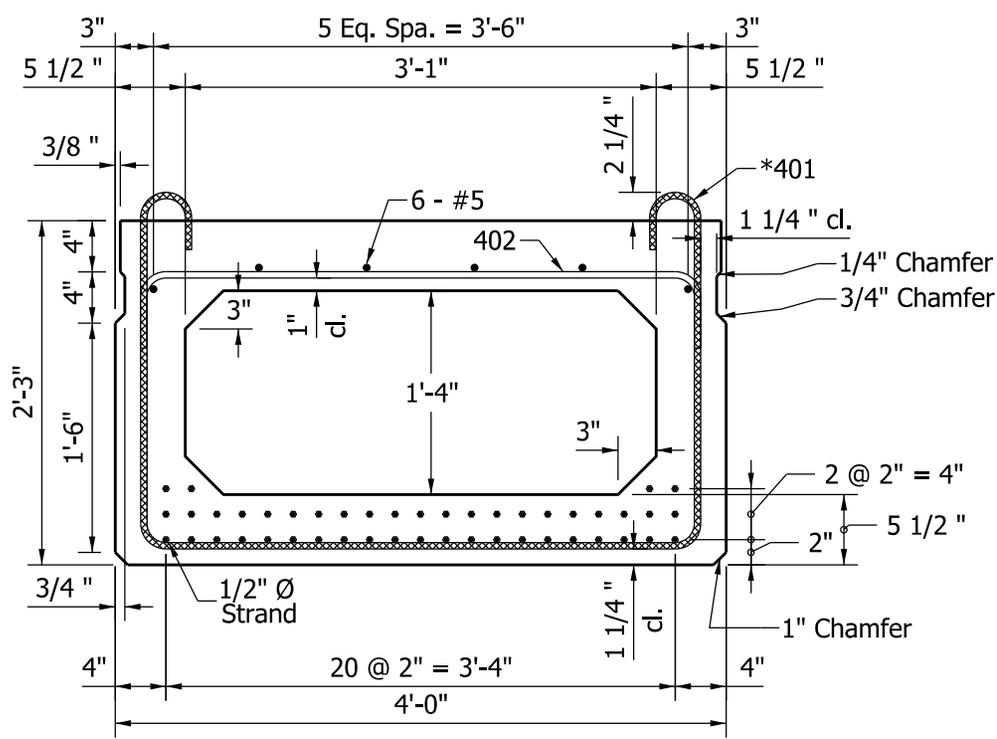


BOX BEAM
TYPE CB 21 x 48

Figure 406-15 I

BEAM PROPERTIES	
A_B	= 713 in ²
I_B	= 66,216 in ⁴
STB	= 4,865 in ³
SBB	= 4,945 in ³
Y_{TB}	= 13.61 in
Y_{BB}	= 13.39 in
Wt.	= 743 lbs/ft

NOTES:
 1.  *DENOTES EPOXY-COATED BAR



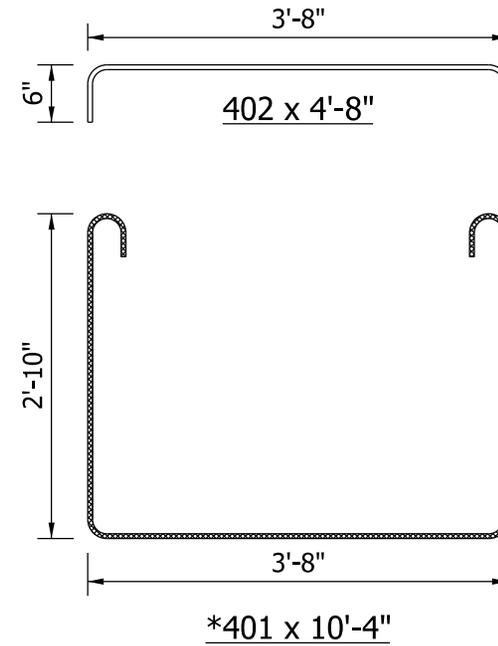
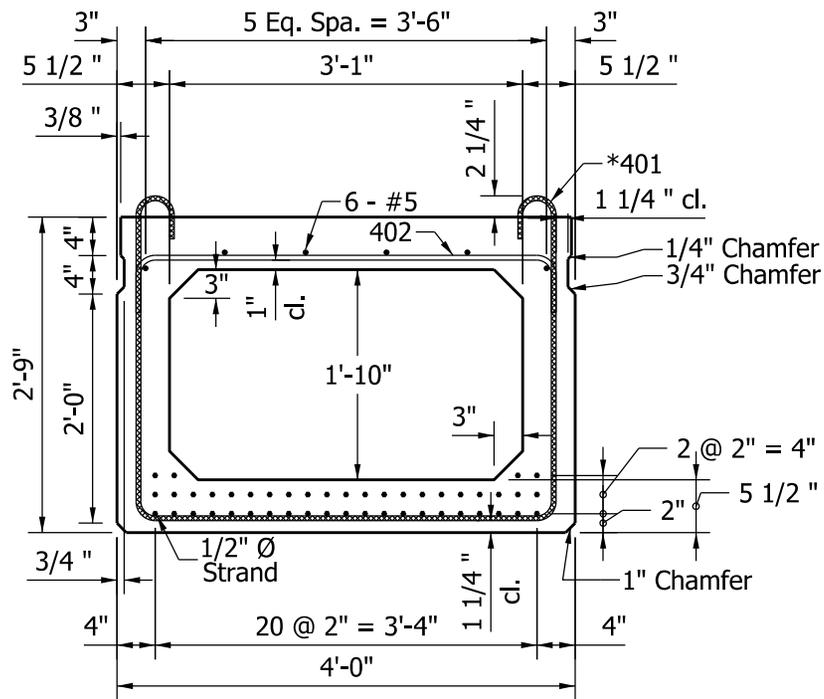
**BOX BEAM
 TYPE CB 27 x 48**

Figure 406-15J

BEAM PROPERTIES	
A_B	= 779 in ²
I_B	= 111,384 in ⁴
STB	= 6,694 in ³
SBB	= 6,808 in ³
Y_{TB}	= 16.64 in
Y_{BB}	= 16.36 in
Wt.	= 811 lbs/ft

NOTES:

1.  *DENOTES EPOXY-COATED BAR



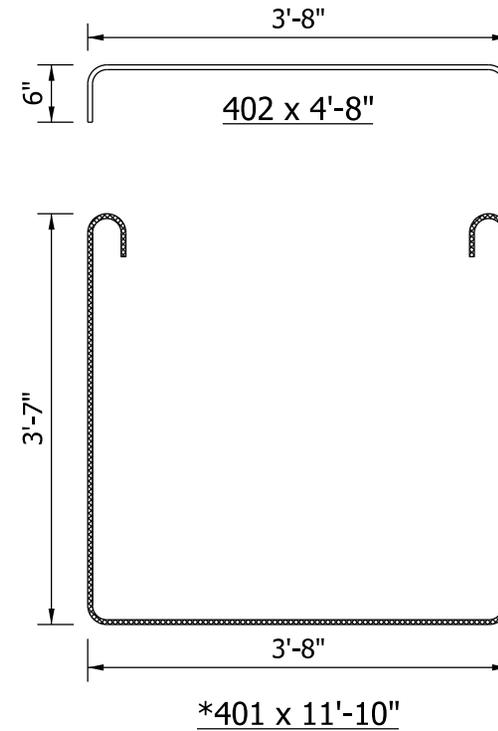
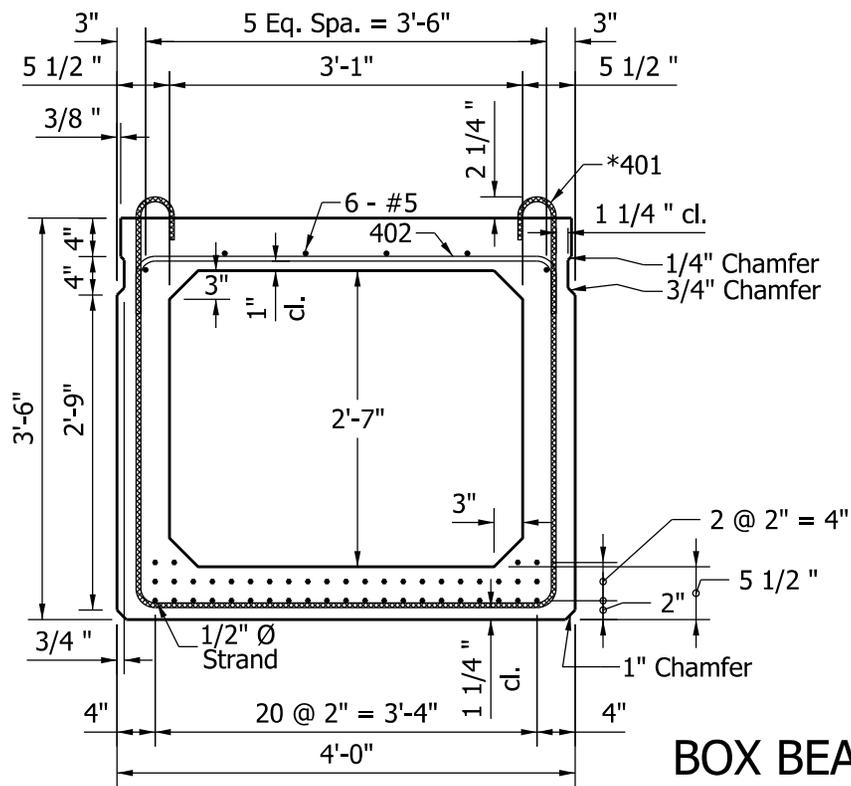
BOX BEAM
TYPE CB 33 x 48

Figure 406-15K

BEAM PROPERTIES	
A_B	= 878 in ²
I_B	= 205,798 in ⁴
STB	= 9,721 in ³
SBB	= 9,880 in ³
Y_{TB}	= 21.17 in
Y_{BB}	= 20.83 in
Wt.	= 915 lbs/ft

NOTES:

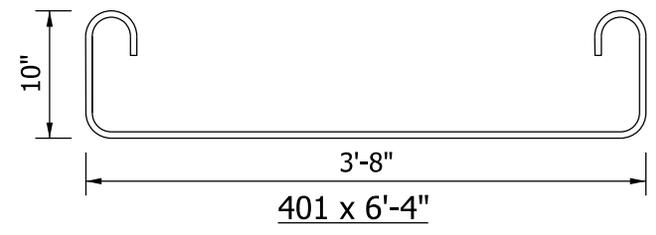
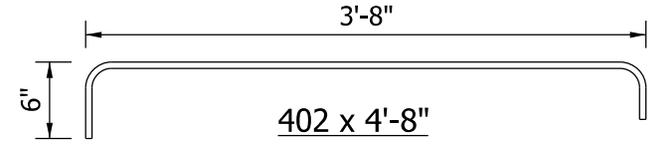
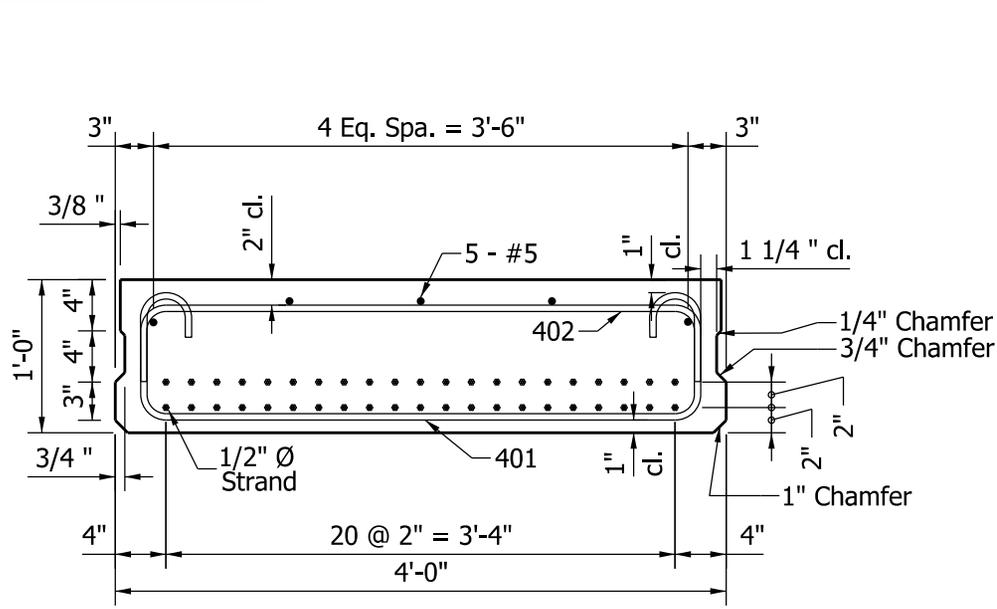
1.  *DENOTES EPOXY-COATED BAR



**BOX BEAM
TYPE CB 42 x 48**

Figure 406-15L

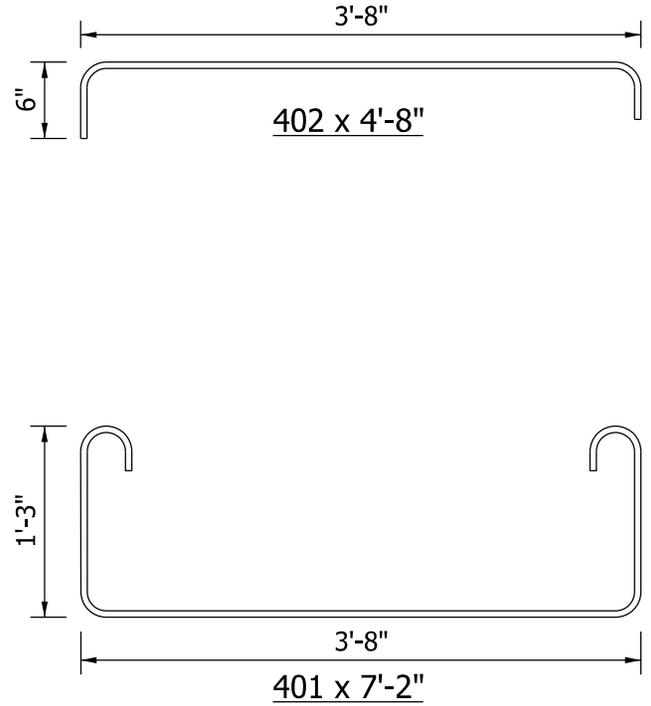
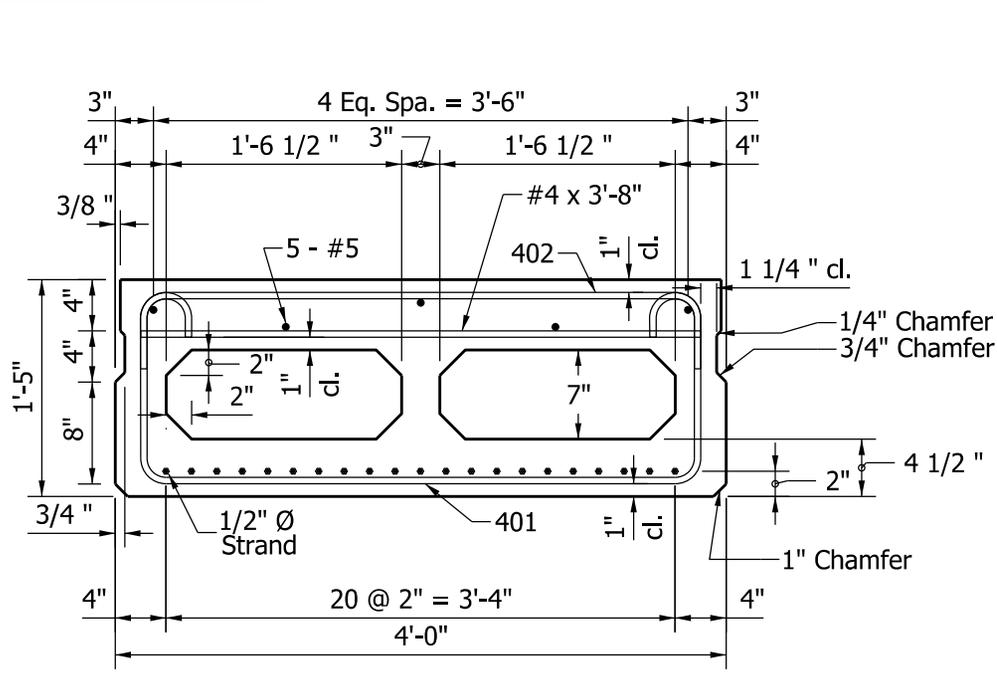
BEAM PROPERTIES	
A_B	= 567 in ²
I_B	= 6,852 in ⁴
STB	= 1,138 in ³
SBB	= 1,146 in ³
Y_{TB}	= 6.02 in
Y_{BB}	= 5.98 in
Wt.	= 591 lbs/ft



**BOX BEAM
TYPE WS 12 x 48**

Figure 406-15M

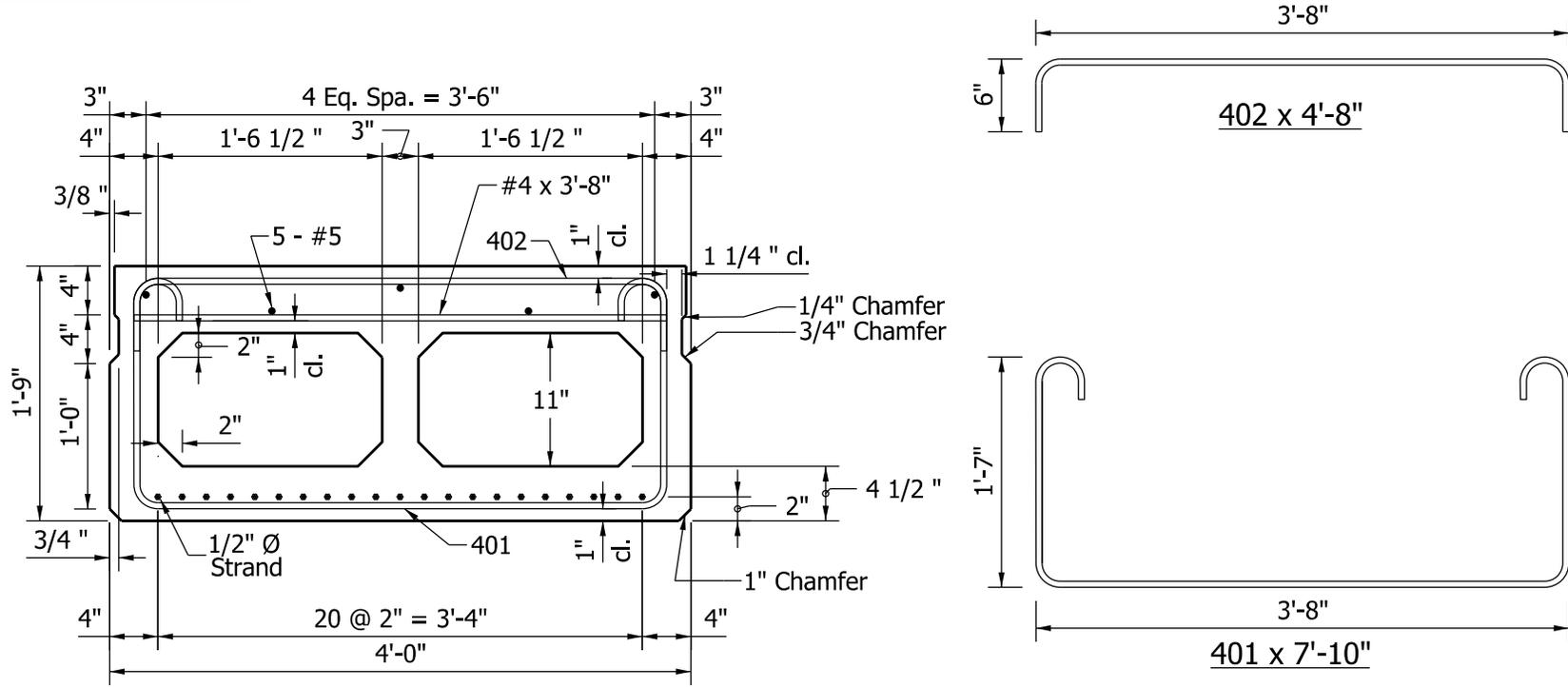
BEAM PROPERTIES	
A_B	= 564 in ²
I_B	= 18,467 in ⁴
S_{TB}	= 2,212 in ³
S_{BB}	= 2,135 in ³
Y_{TB}	= 8.35 in
Y_{BB}	= 8.65 in
Wt.	= 588 lbs/ft



**BOX BEAM
TYPE WS 17 x 48**

Figure 406-15N

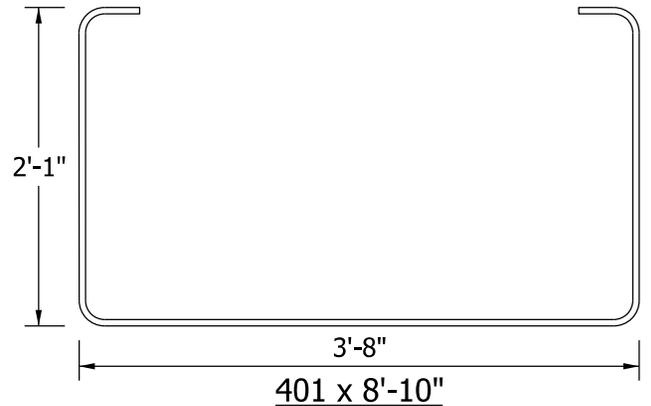
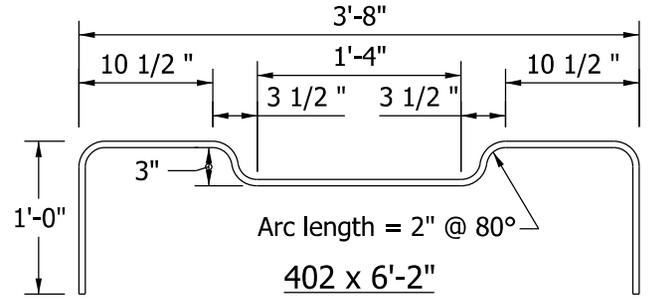
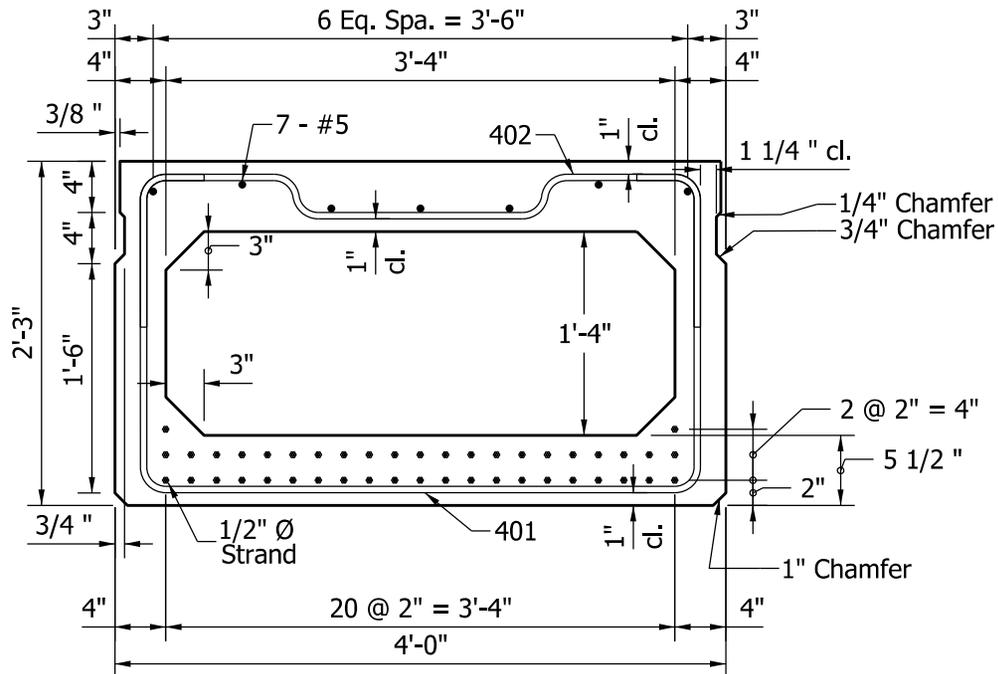
BEAM PROPERTIES	
A_B	= 608 in ²
I_B	= 32,826 in ⁴
S_{TB}	= 3,199 in ³
S_{BB}	= 3,056 in ³
Y_{TB}	= 10.26 in
Y_{BB}	= 10.74 in
Wt.	= 633 lbs/ft



**BOX BEAM
TYPE WS 21 x 48**

Figure 406-15 O

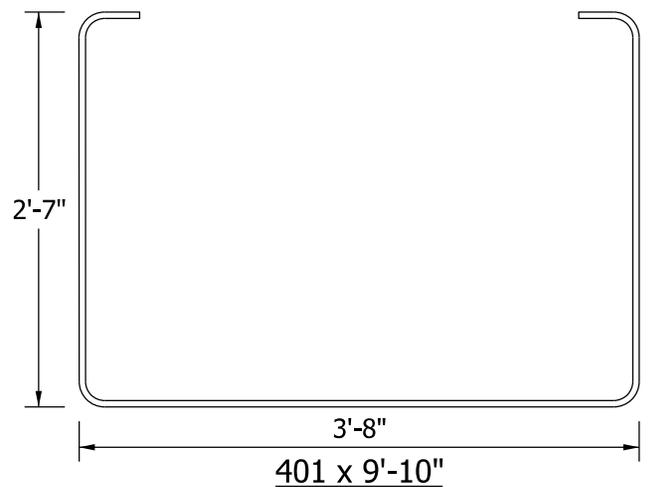
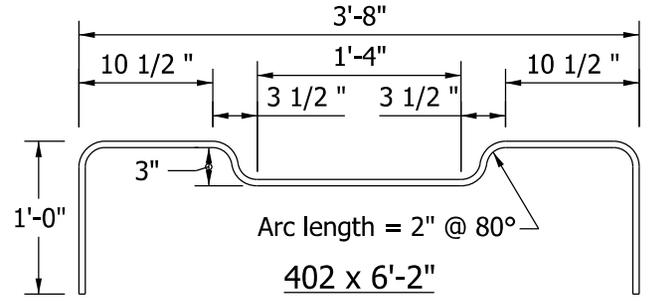
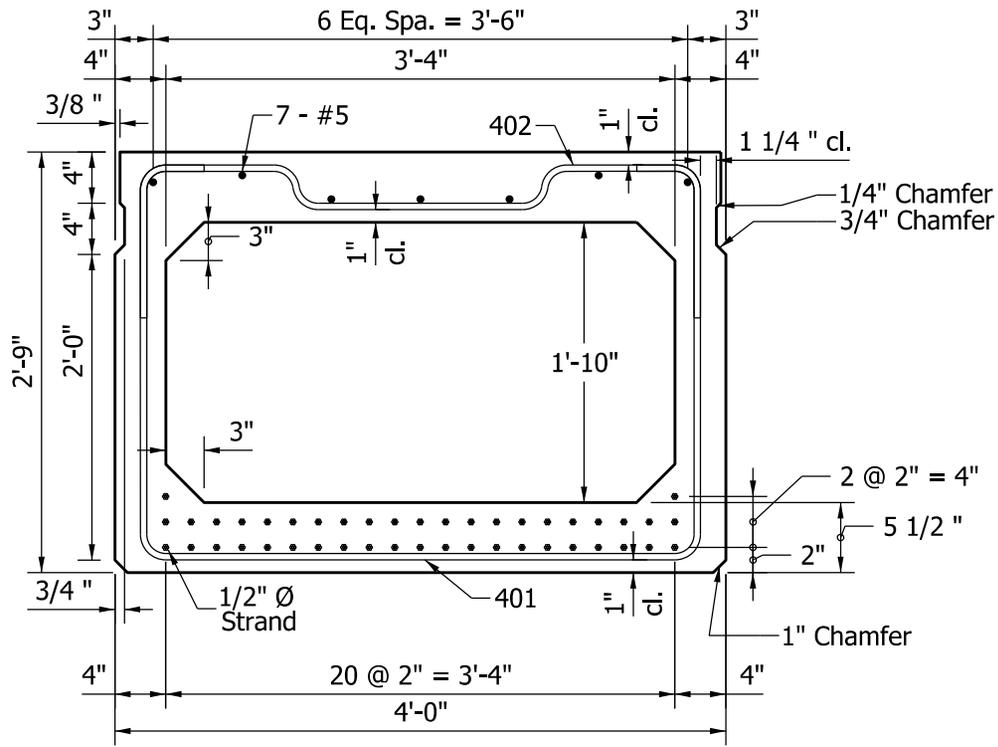
BEAM PROPERTIES	
A_B	= 713 in ²
I_B	= 66,216 in ⁴
STB	= 4,865 in ³
SBB	= 4,945 in ³
Y_{TB}	= 13.61 in
Y_{BB}	= 13.39 in
Wt.	= 743 lbs/ft



**BOX BEAM
TYPE WS 27 x 48**

Figure 406-15P

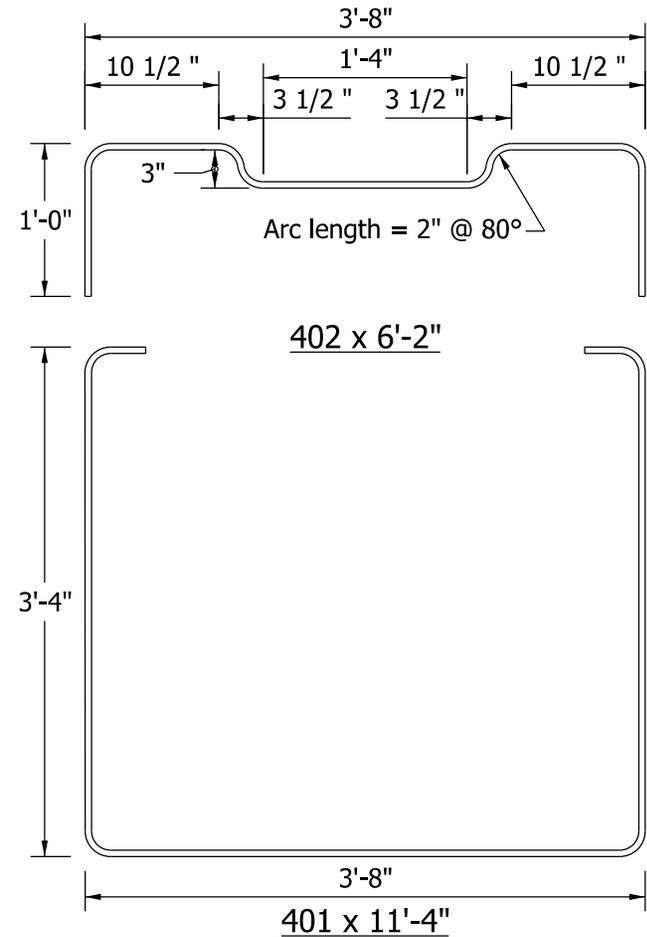
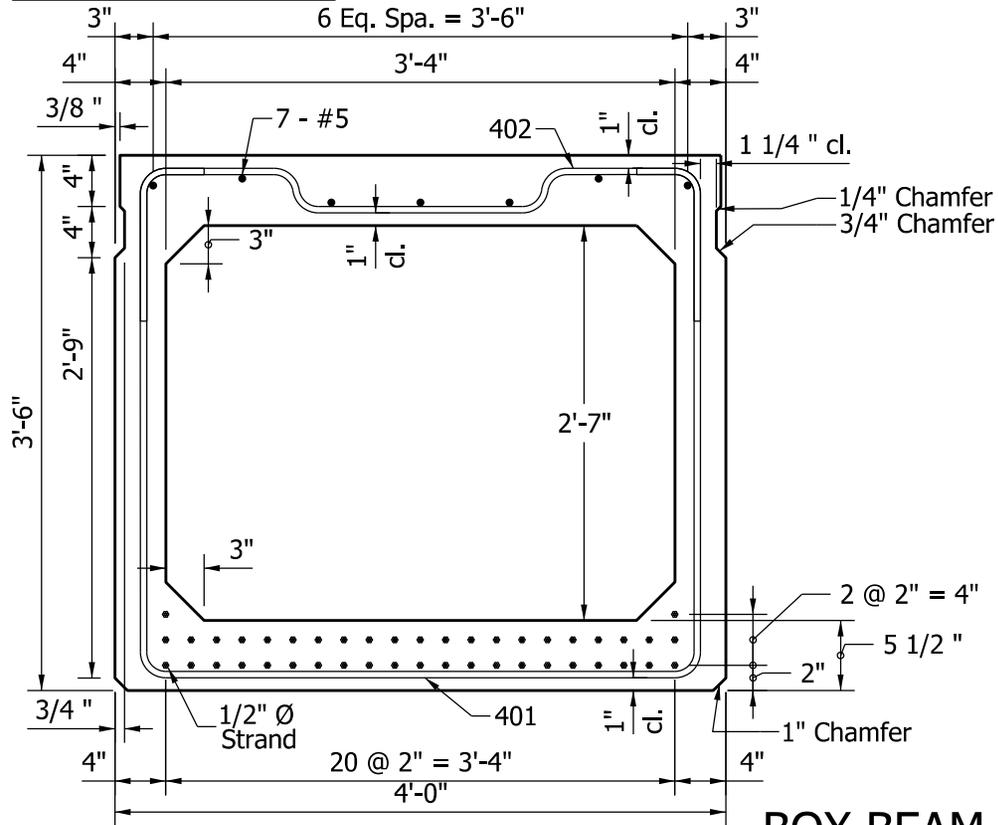
BEAM PROPERTIES	
A_B	= 779 in ²
I_B	= 111,384 in ⁴
STB	= 6,694 in ³
SBB	= 6,808 in ³
Y_{TB}	= 16.64 in
Y_{BB}	= 16.36 in
Wt.	= 811 lbs/ft



**BOX BEAM
TYPE WS 33 x 48**

Figure 406-15Q

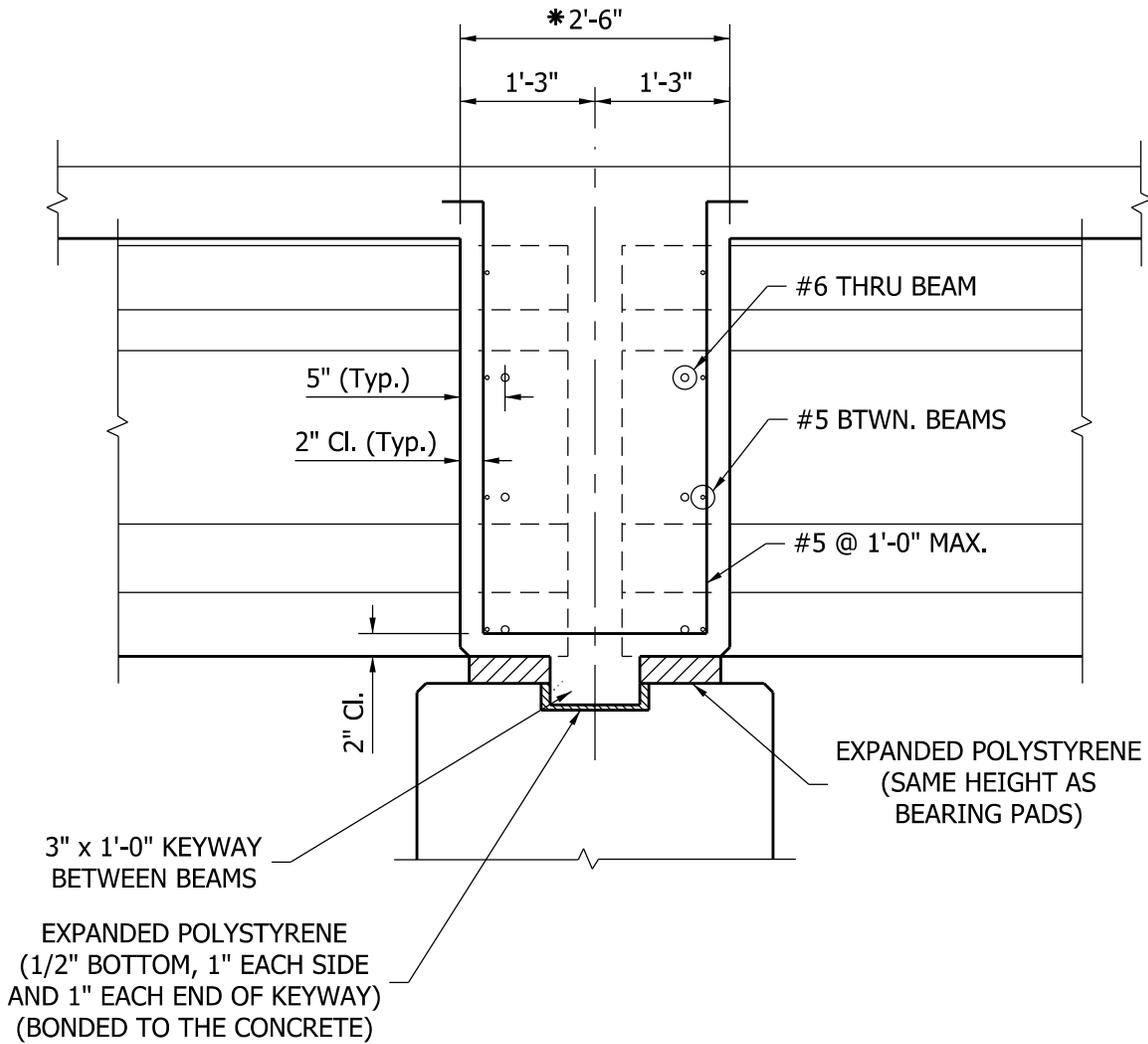
BEAM PROPERTIES	
A_B	= 878 in ²
I_B	= 205,798 in ⁴
S_{TB}	= 9,721 in ³
S_{BB}	= 9,880 in ³
Y_{TB}	= 21.17 in
Y_{BB}	= 20.83 in
Wt.	= 915 lbs/ft



**BOX BEAM
TYPE WS 42 x 48**

Figure 406-15R

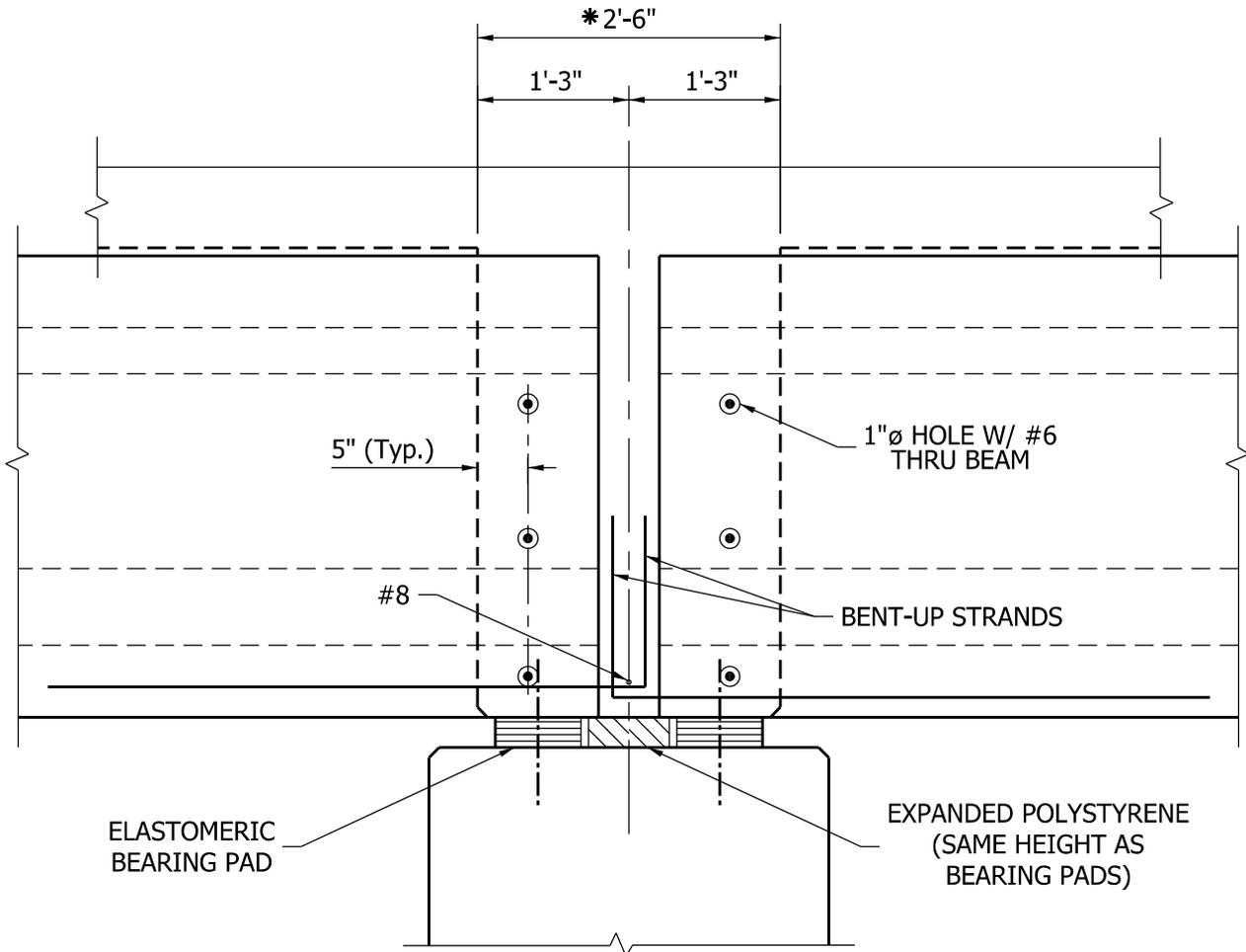
*THIS IS A MINIMUM DIMENSION.



I-BEAM PIER DIAPHRAGM SECTION BETWEEN BEAMS

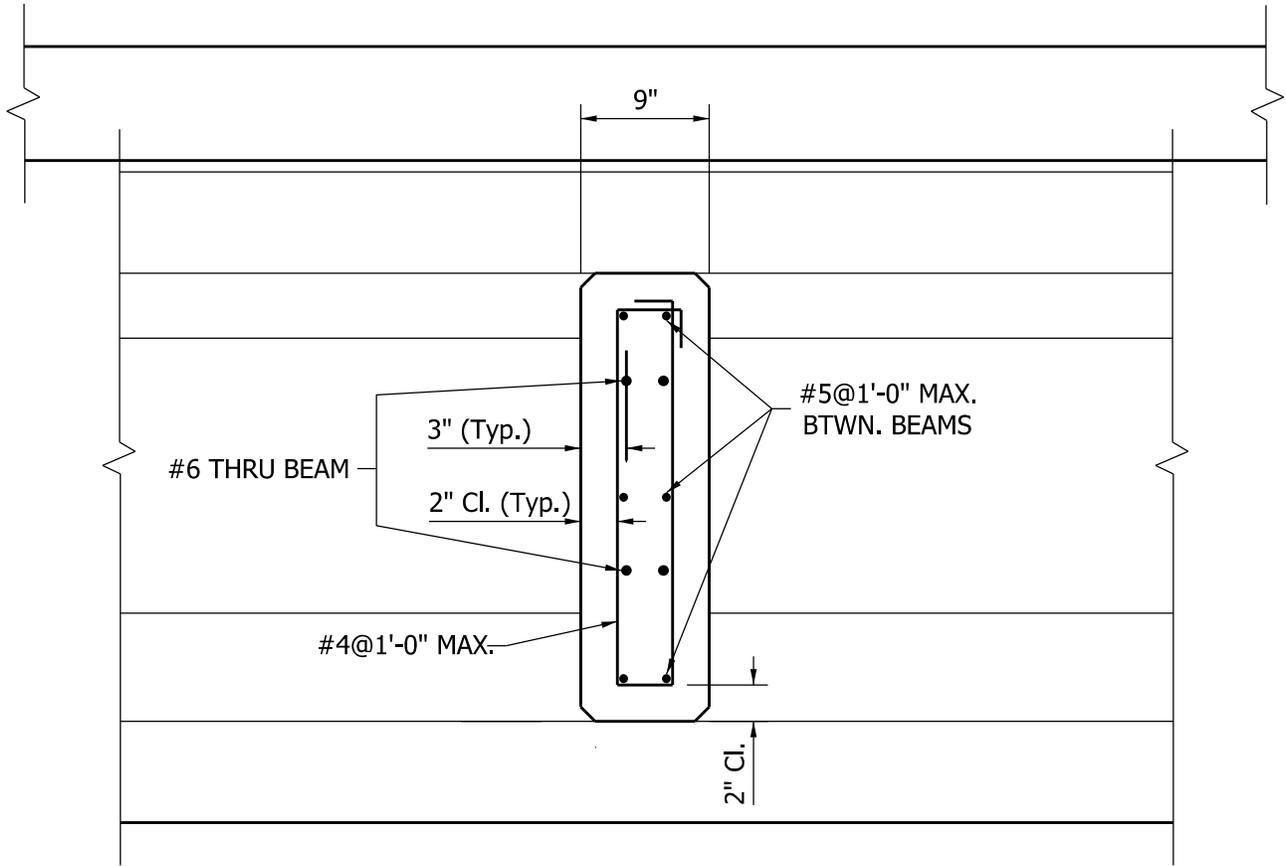
Figure 406-16A

*THIS IS A MINIMUM DIMENSION.



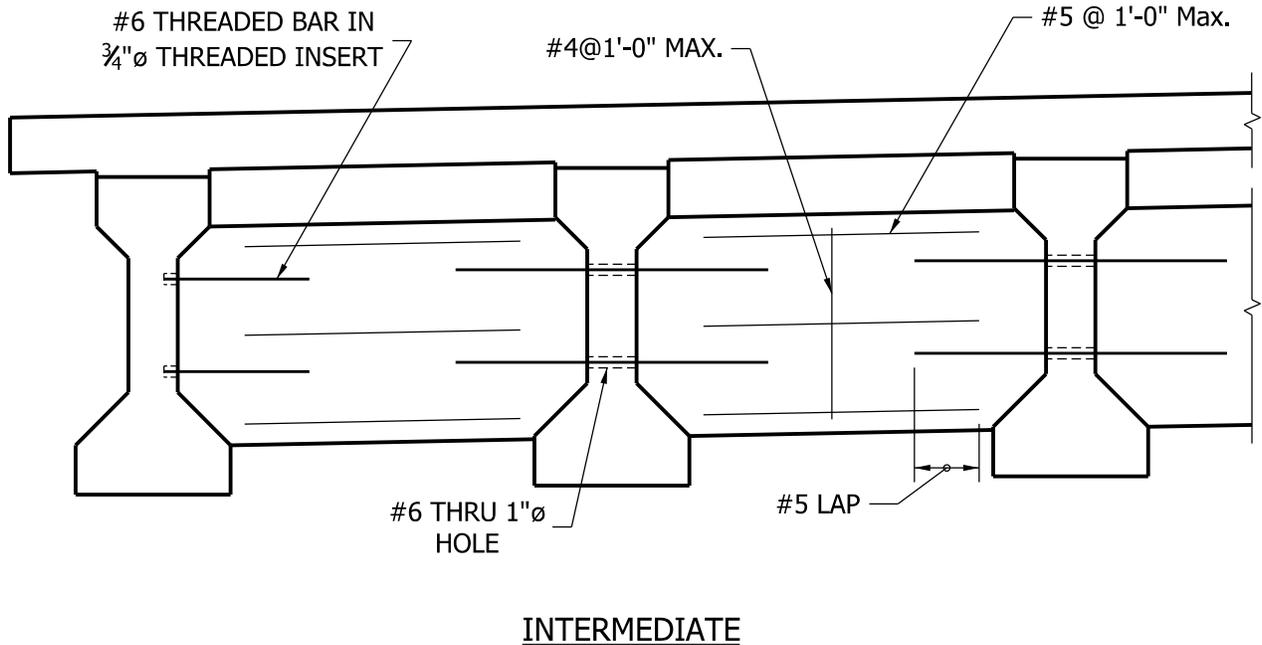
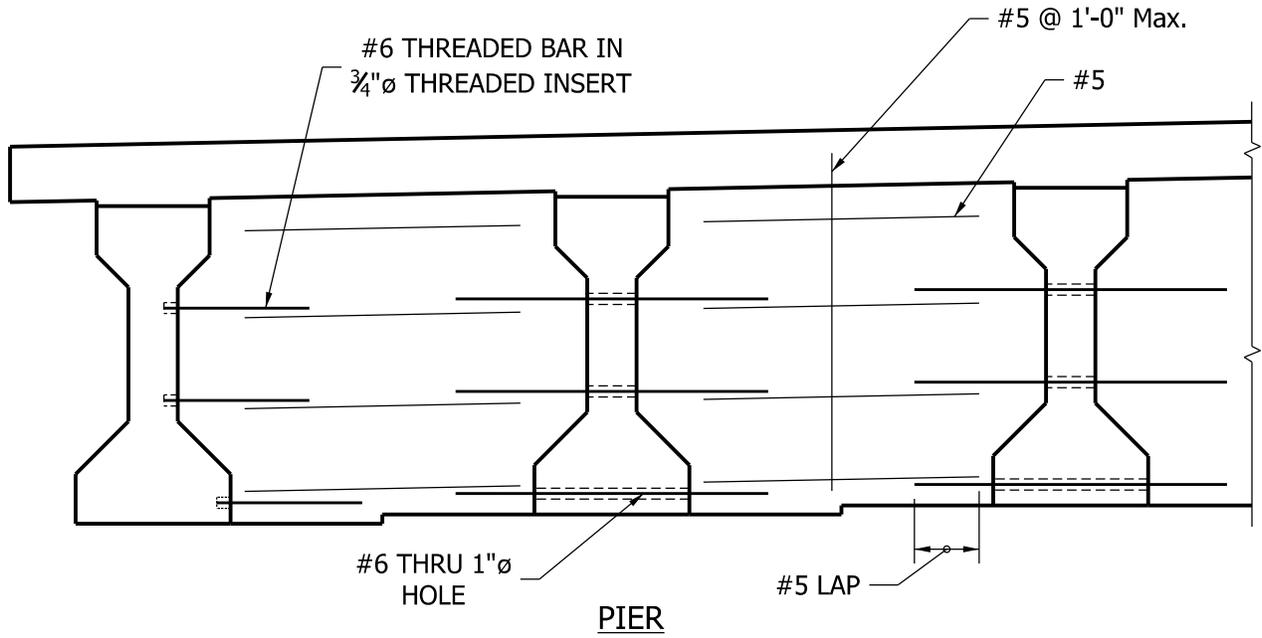
I-BEAM PIER DIAPHRAGM SECTION AT BEAMS

Figure 406-16B



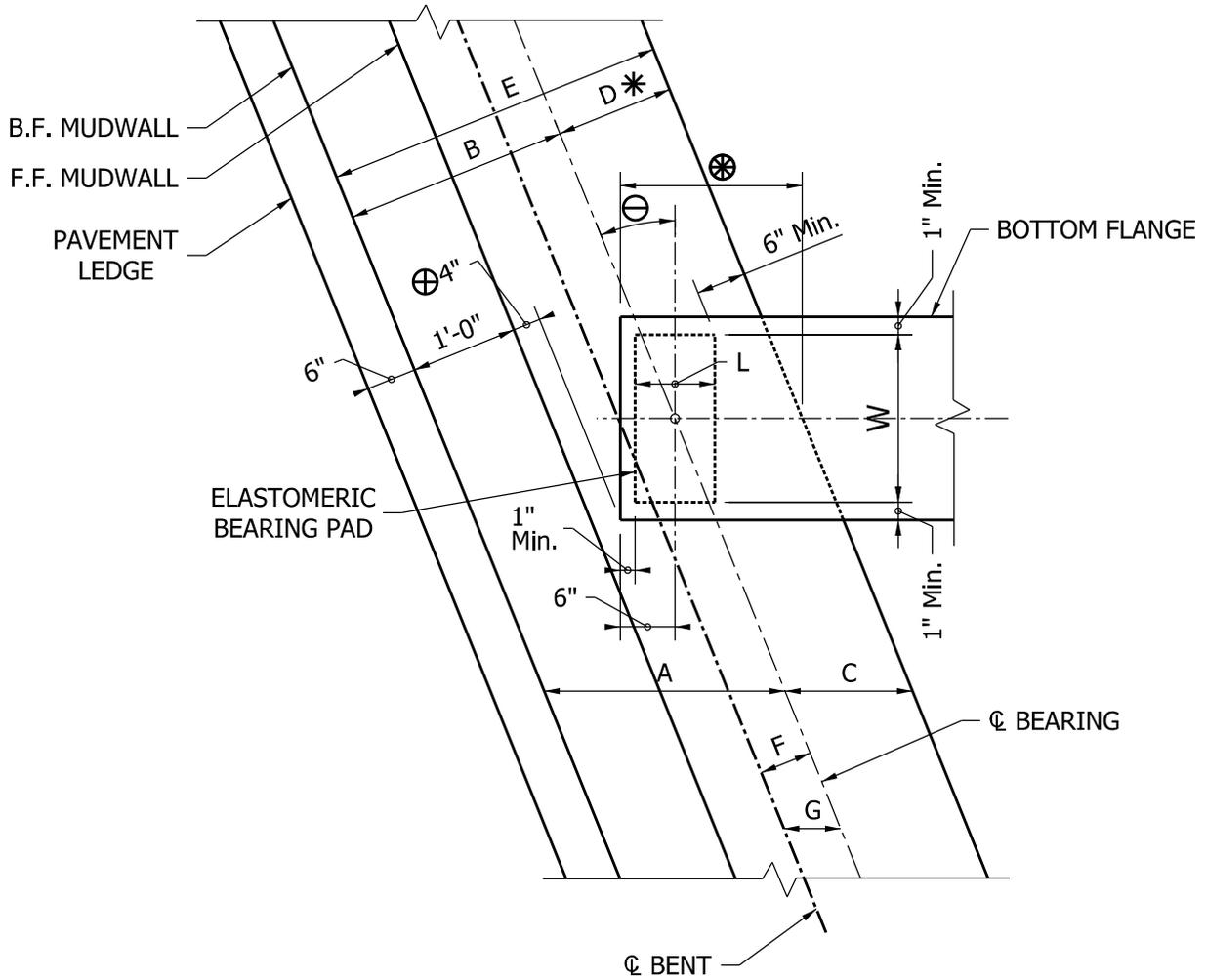
I-BEAM
INTERMEDIATE DIAPHRAGM

Figure 406-16C



I-BEAM DIAPHRAGMS

Figure 406-16D

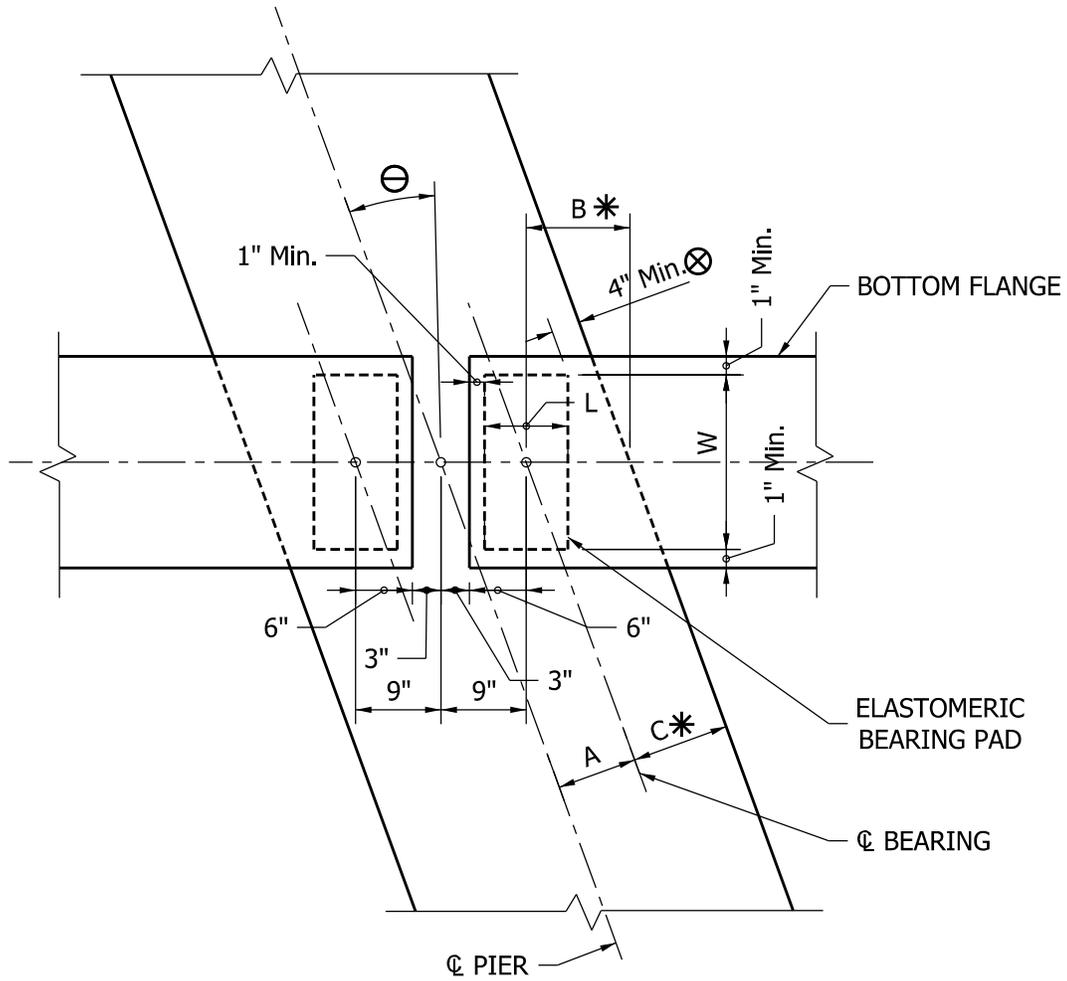


$A = (1'-4") \sec \Theta + 10" + 0.5 (L + W \tan \Theta)$	$E = B + D$
$B = A \cos \Theta$	ACTUAL $D = E - B$
$C = 0.5 (L + W \tan \Theta) + \sec \Theta$	$F = B - (0.5E)$
$D = C \cos \Theta$	$G = F \sec \Theta$

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊗ CHECK SEISMIC MINIMUM SUPPORT LENGTH FOR EXPANSION BENT.
- ⊕ THIS DIMENSION SHOULD BE INCREASED FOR LARGE EXPANSION LENGTH.

I-BEAM: END BENT CAP SIZING AND BEARING LAYOUT DETAILS

Figure 406-16E



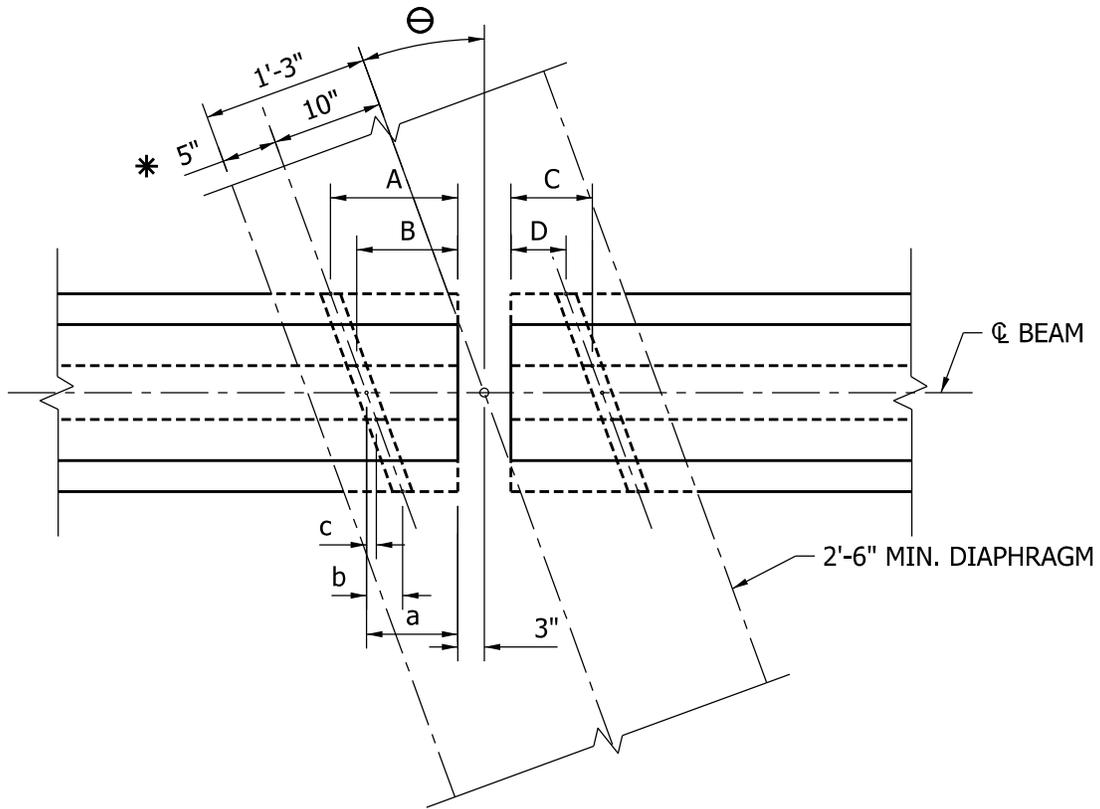
$A = 9'' \cos \Theta$
 $B = 0.5 (L + W \tan \Theta) + 4'' \sec$
 $C = B \cos \Theta$
 CAP WIDTH = $2AC$
 ACTUAL C = $1/2$ CAP WIDTH - A

* USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"

⊗ USE 6" FOR PIER BELOW EXPANSION JOINT.

I BEAM: PIER CAP SIZING AND BEARING LAYOUT DETAILS

Figure 406-16F



$$a = (10'' - \cos \Theta) - 3''$$

$$b = 1/2 \text{ Bottom Flange Width } (\tan \Theta)$$

$$c = 1/2 \text{ Web Thickness } (\tan \Theta)$$

$$A = a + b$$

$$B = a + c$$

$$C = a - c$$

$$D = a - b$$

NOTES:

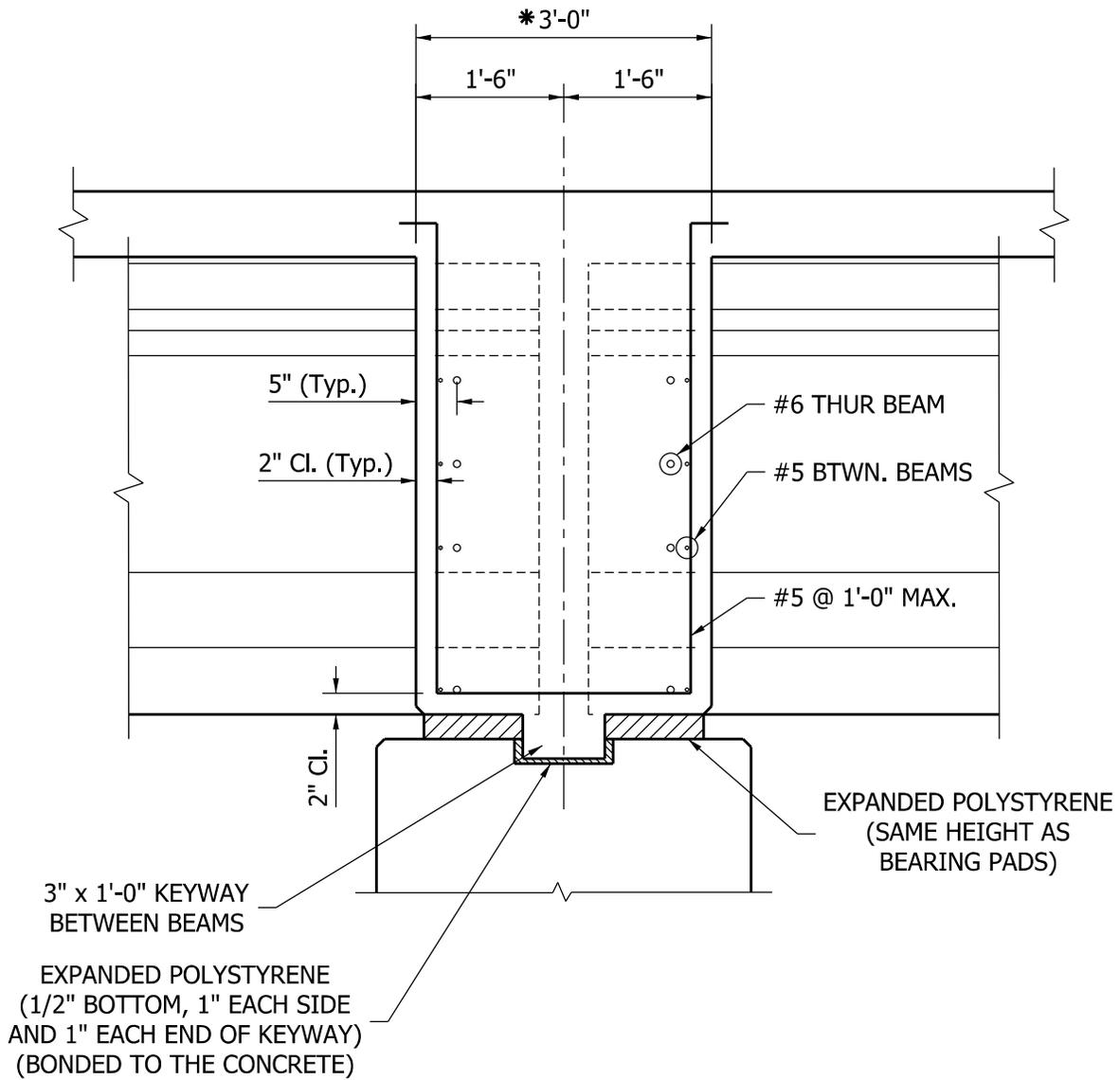
1. IF $D < 2''$ USE LARGER DIAPHRAGM.
2. A MINUS B AND C MINUS D SHOULD BE MADE EQUAL

* THIS DIMENSION WILL INCREASE OR DECREASE SLIGHTLY IF ENDS OF BEAMS ARE NOT VERTICAL. SEE SECTION 406-12.0 FOR ADDITIONAL INFORMATION.

I-BEAM HOLES AT PIER DIAPHRAGM

Figure 406-16G

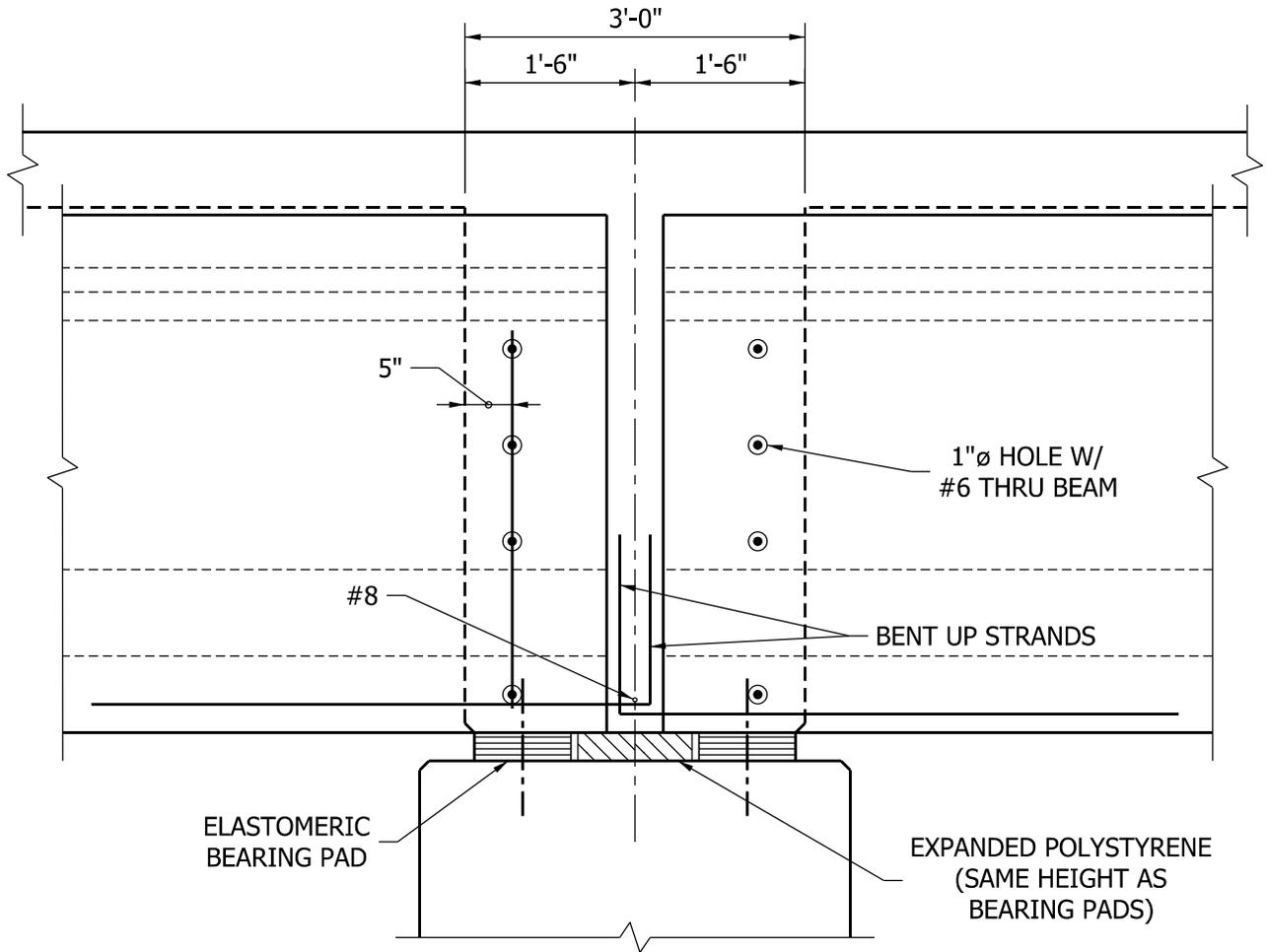
*THIS IS A MINIMUM DIMENSION.



BULB-TEE PIER DIAPHRAGM SECTION BETWEEN BEAMS

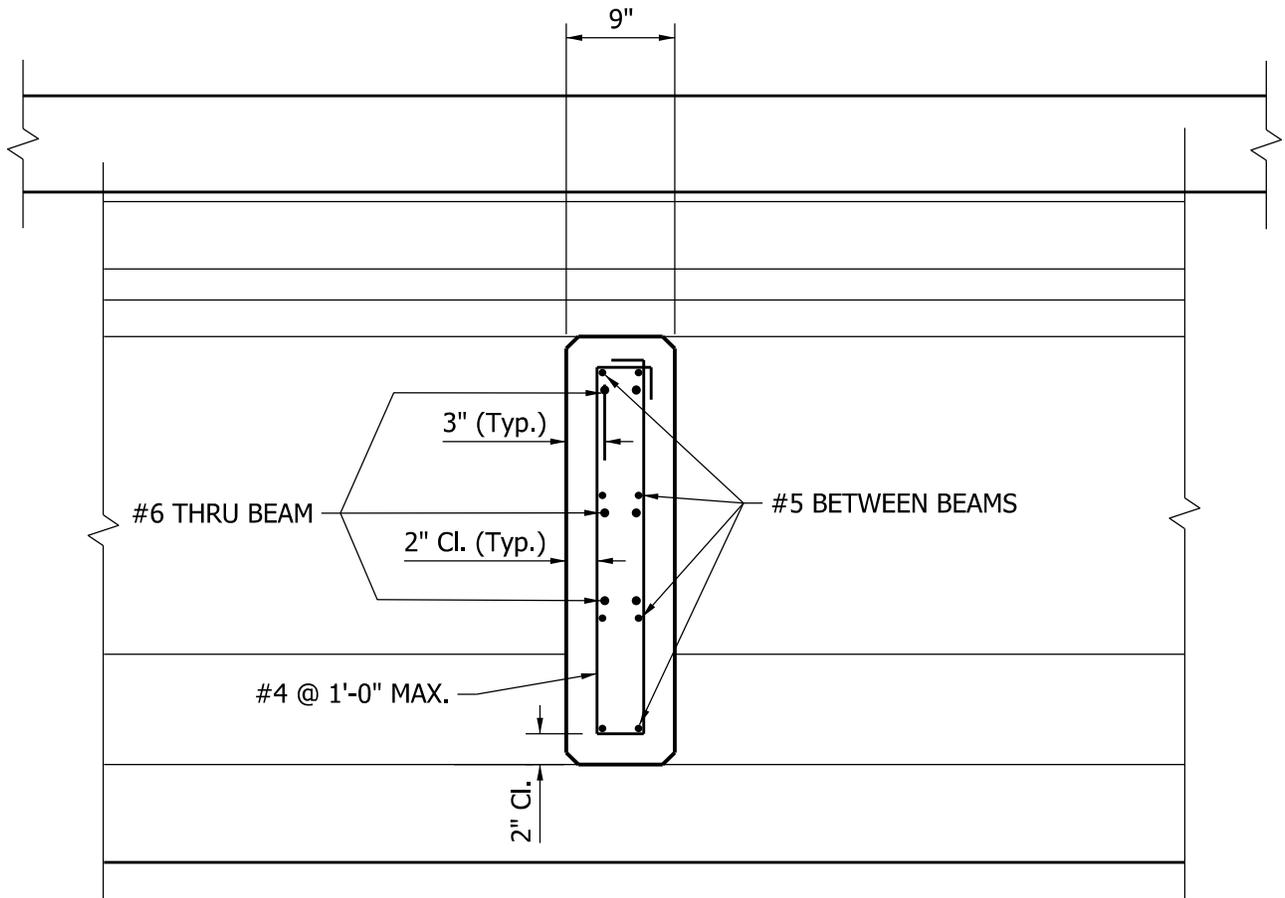
Figure 406-16H

* THIS IS A MINIMUM DIMENSION.



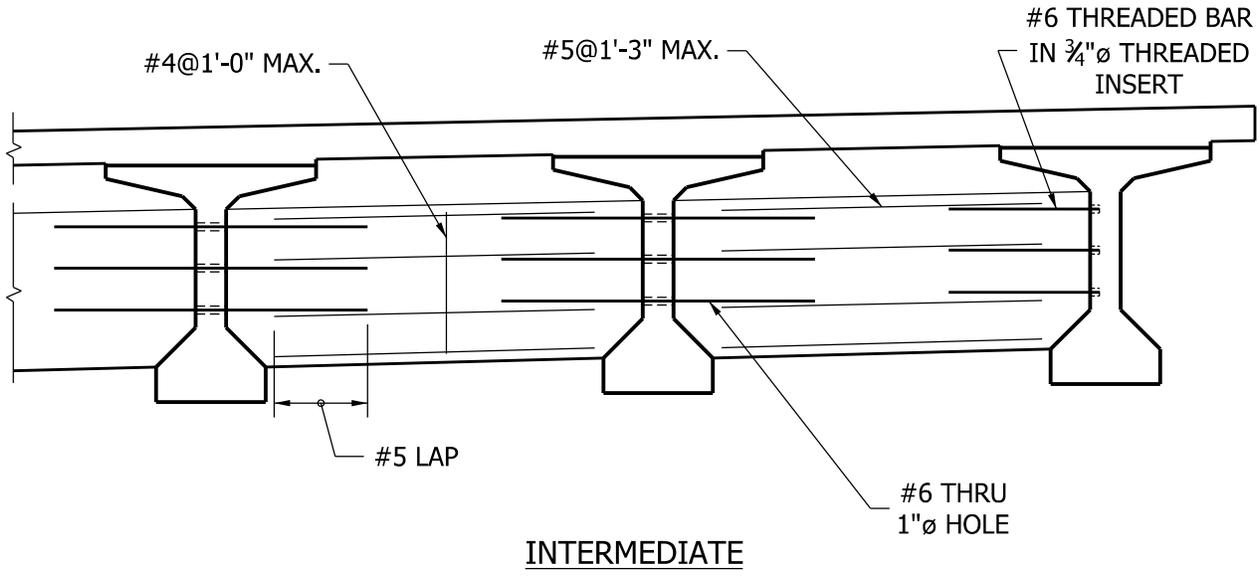
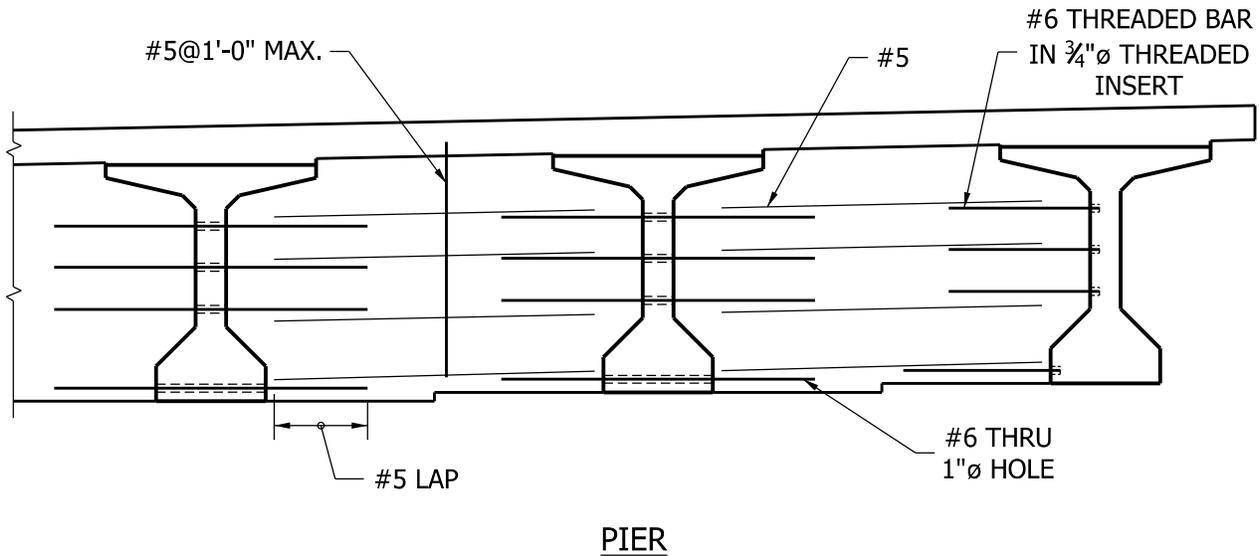
BULB-TEE PIER DIAPHRAGM SECTION AT BEAMS

Figure 406-16 I



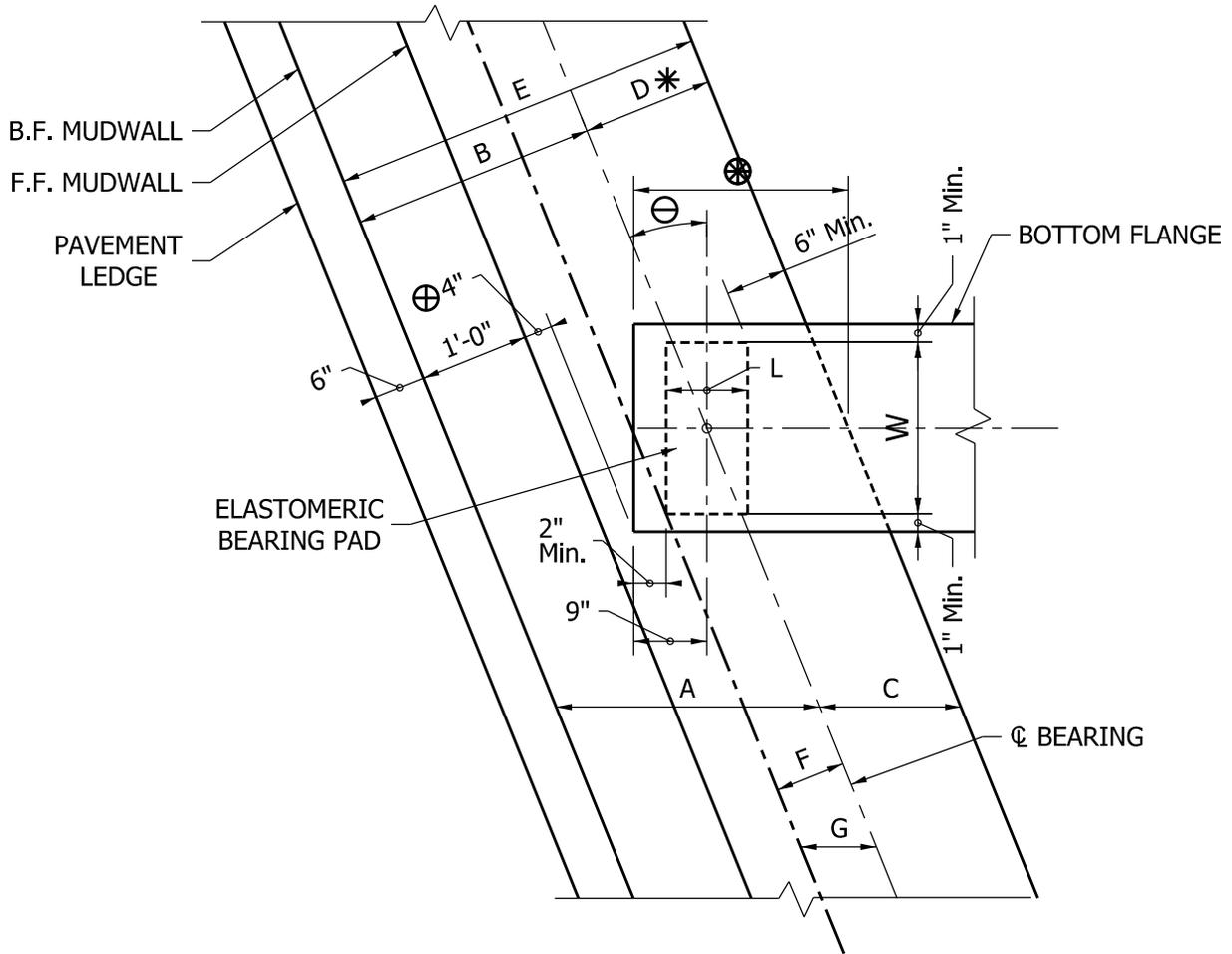
**BULB-TEE
INTERMEDIATE DIAPHRAGM**

Figure 406-16J



**BULB-TEE
DIAPHRAGM**

Figure 406-16K



$$A = (1'-4") \sec \Theta + 9" + 0.5 (L + W \tan \Theta)$$

$$B = A \cos \Theta$$

$$C = 0.5 (L + W \tan \Theta) + \sec$$

$$D = C \cos \Theta$$

$$E = B + D$$

$$\text{ACTUAL } D = E - B$$

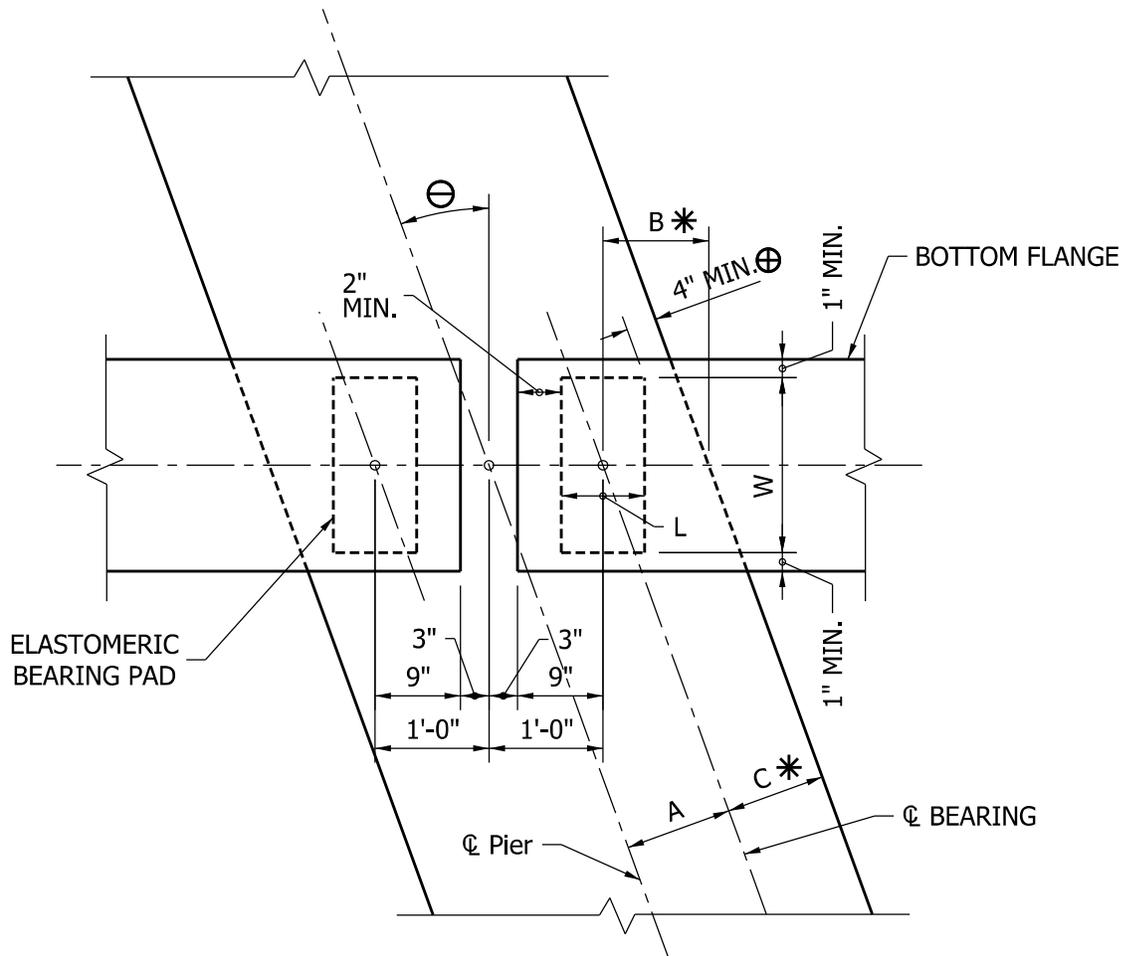
$$F = B - (0.5E)$$

$$G = F \sec \Theta$$

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊗ CHECK SEISMIC MINIMUM SUPPORT LENGTH FOR EXPANSION BENT.
- ⊕ THIS DIMENSION SHOULD BE INCREASED FOR LARGE EXPANSION LENGTH.

BULB-TEE: END BENT CAP SIZING AND BEARING LAYOUT DETAILS

Figure 406-16L

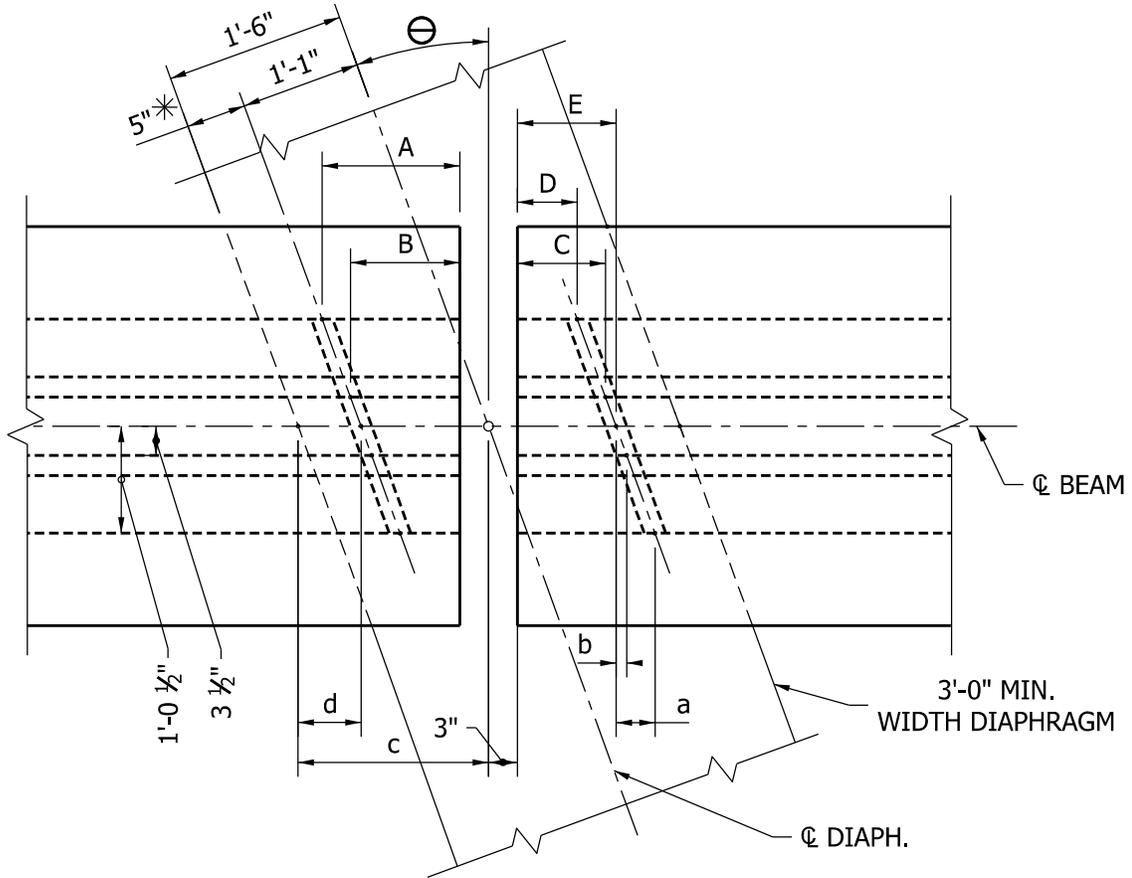


$A = 1 \cos \Theta$
 $B = 0.5 (L + W \tan \Theta) + 4'' \sec \Theta$
 $C = B \cos \Theta$
 CAP WIDTH = $2(A+C)$
 ACTUAL C = $1/2$ CAP WIDTH - A

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊕ USE 6" FOR PIER BELOW EXPANSION JOINT

BULB TEE: PIER CAP SIZING AND BEARING LAYOUT DETAILS

Figure 406-16M



$$a = (1'-0 \frac{1}{2}'') (\tan \Theta)$$

$$b = (3 \frac{1}{2}'') (\tan \Theta)$$

$$c = (1'-6'') \sec \Theta$$

$$d = (5'') (\sec \Theta)$$

$$E = (1'-1'') \sec \Theta - 3''$$

$$A = E + a$$

$$B = E + b$$

$$C = E - b$$

$$D = E - a$$

NOTE:

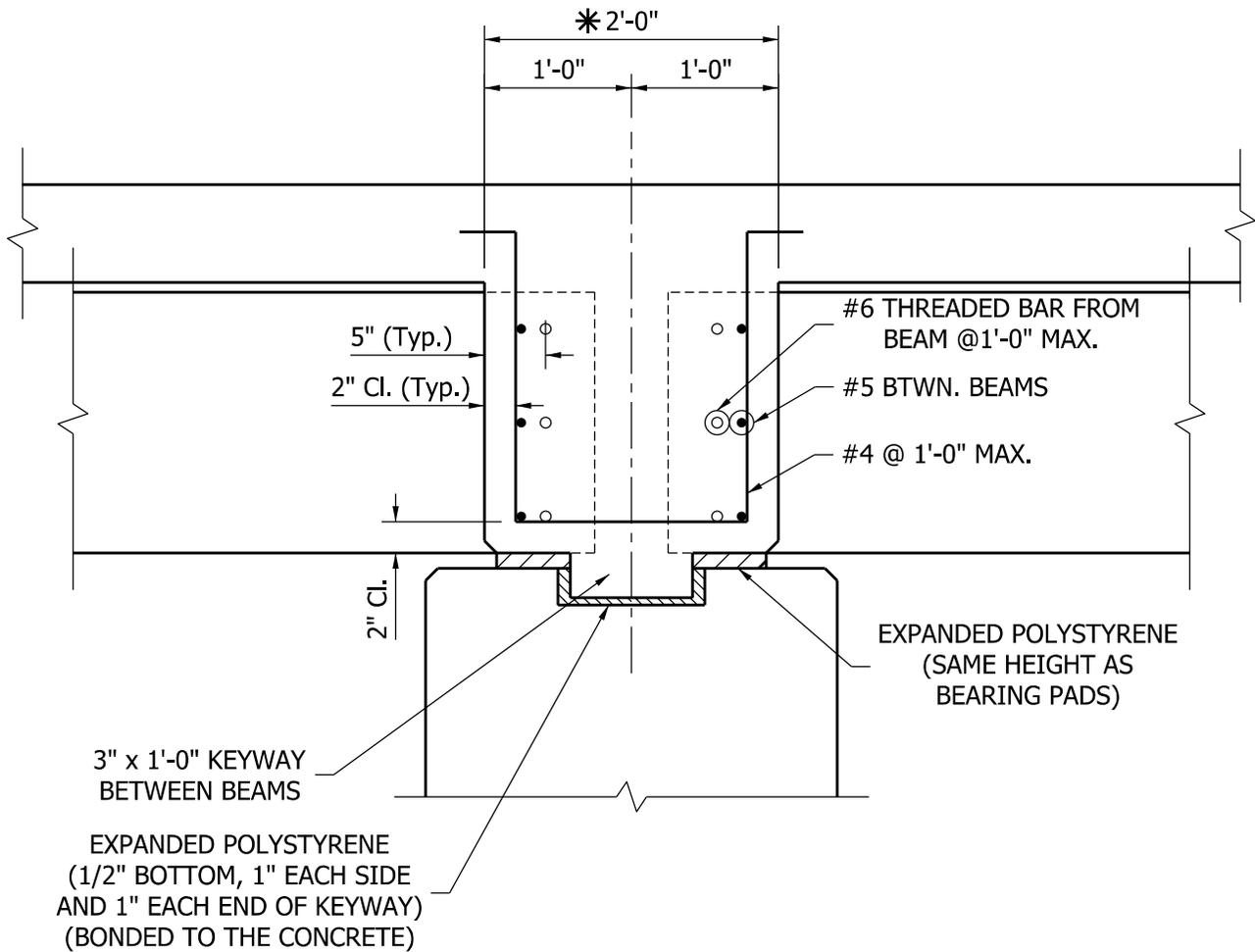
IF D OR d IS < 2" USE LARGER DIAPHRAGM.

* THIS DIMENSION WILL INCREASE OR DECREASE SLIGHTLY IF ENDS OF BEAMS ARE NOT VERTICAL. SEE SECTION 406-12.0 FOR ADDITIONAL INFORMATION.

BULB-TEE HOLES AT PIER DIAPHRAGM

Figure 406-16N

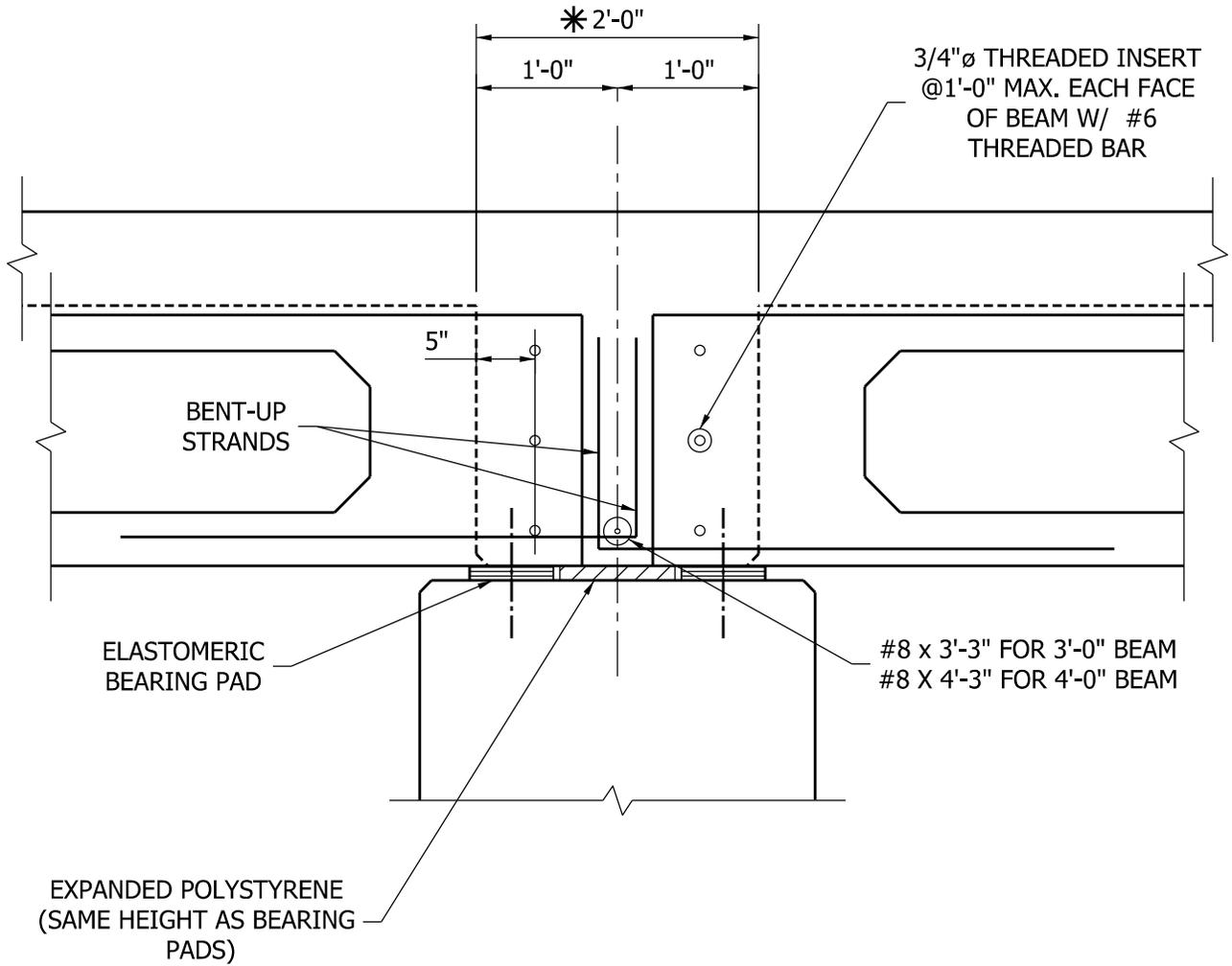
*THIS IS A MINIMUM DIMENSION.



**BOX BEAM PIER DIAPHRAGM FOR SPREAD BEAMS
SECTION BETWEEN BEAMS**

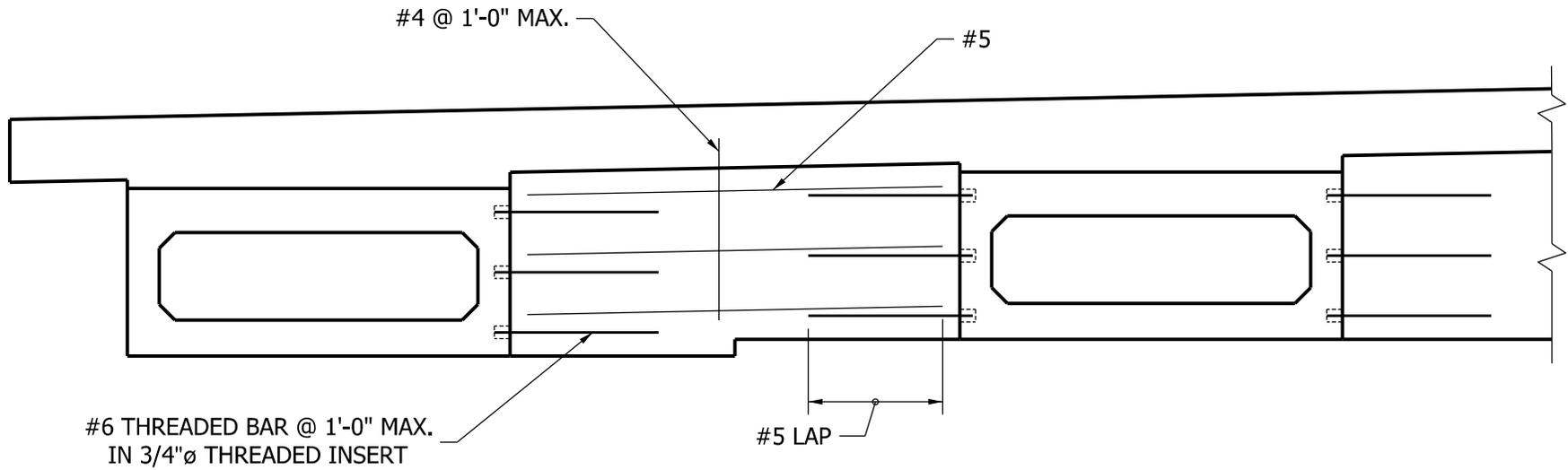
Figure 406-16 O

*THIS IS A MINIMUM DIMENSION.



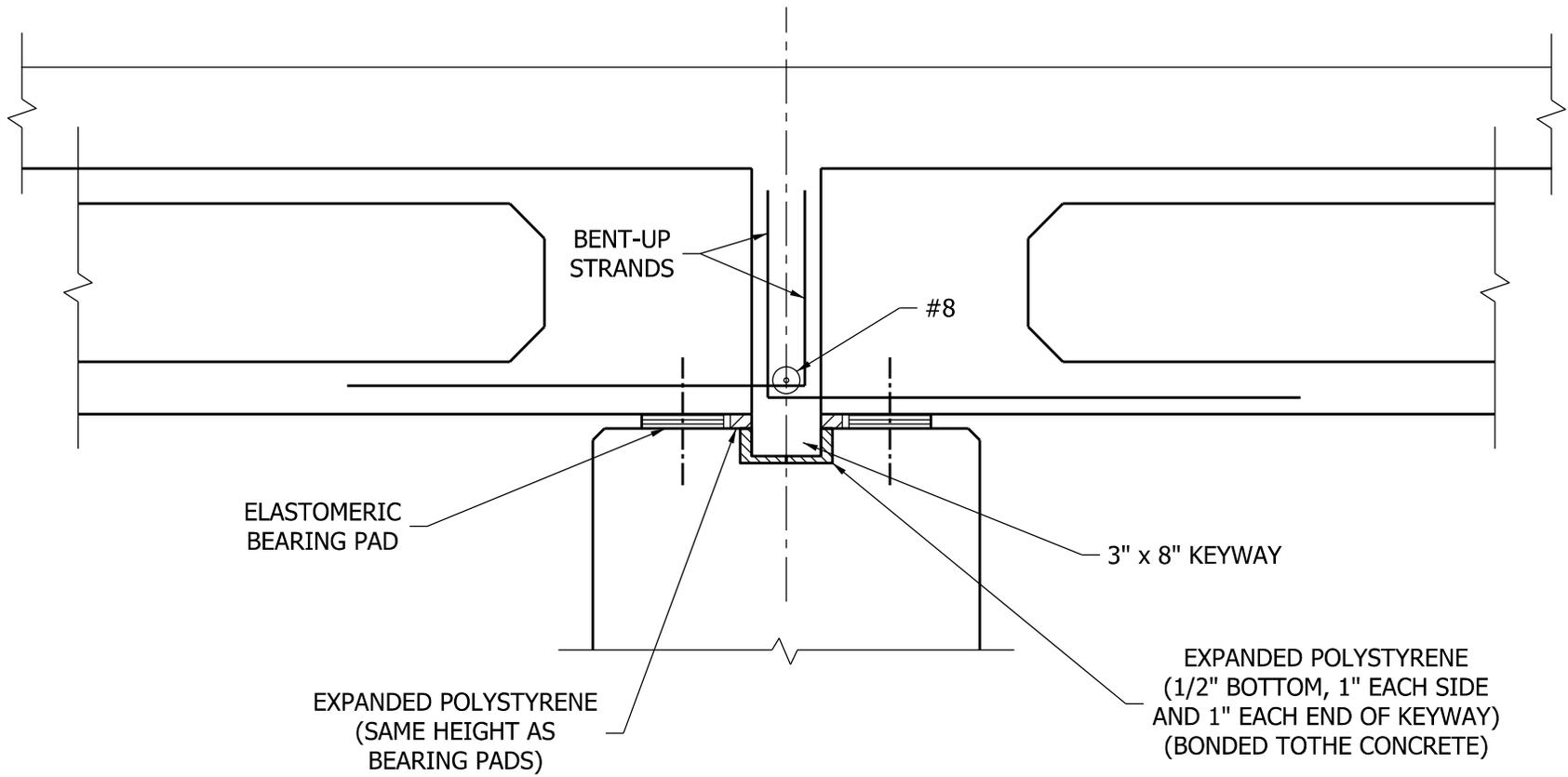
BOX BEAM PIER DIAPHRAGM FOR SPREAD BEAMS SECTION AT BEAMS

Figure 406-16P



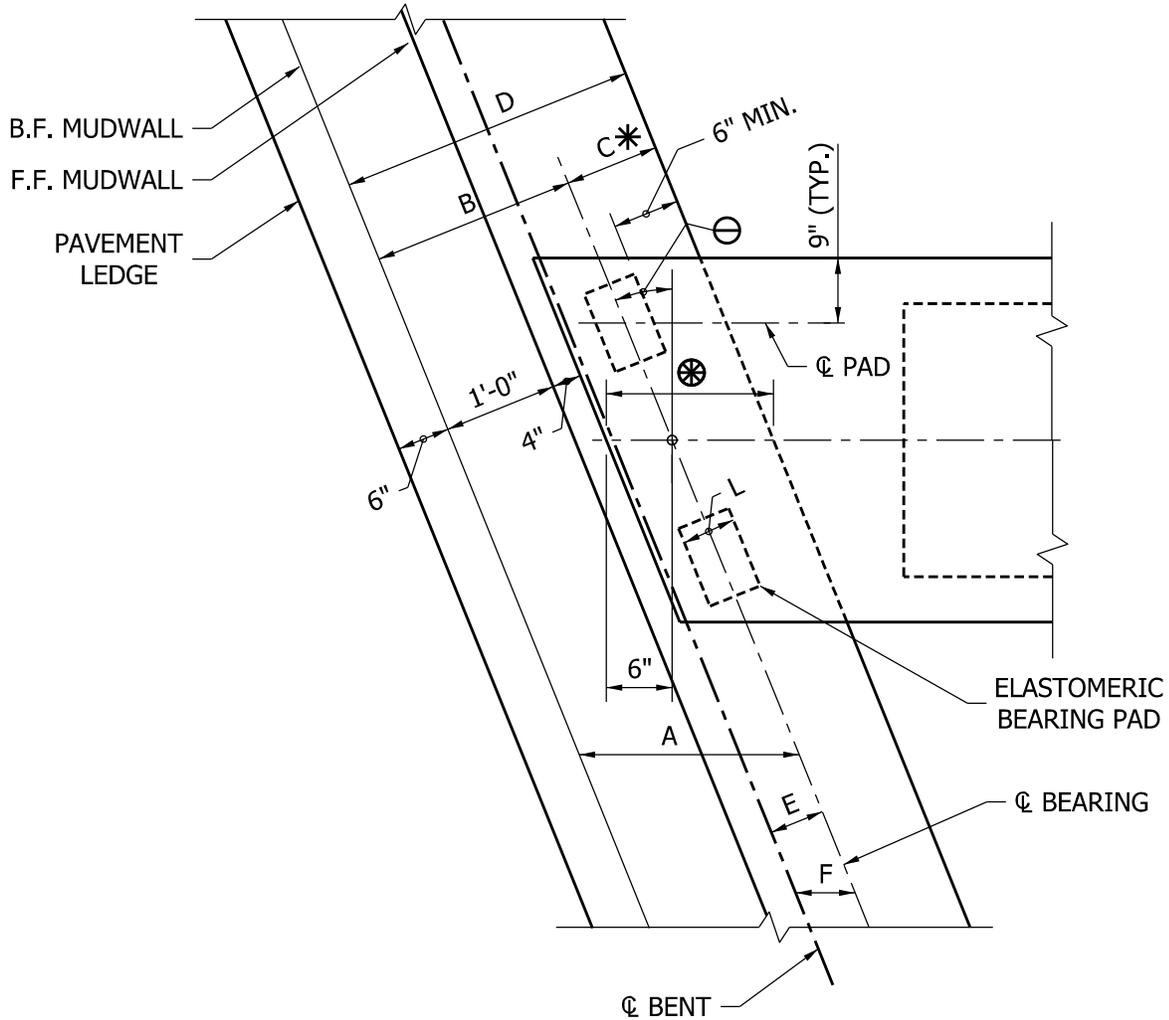
BOX BEAM DIAPHRAGM
AT PIER

Figure 406-16Q



**BOX BEAM
CLOSURE POUR AT PIER
FOR ADJACENT BEAMS**

Figure 406-16R



$$A = (1'-4") \sec \theta + 6"$$

$$B = A \cos \theta$$

$$C = 0.5 L + 6"$$

$$D = B + C$$

$$\text{ACTUAL } C = D - B$$

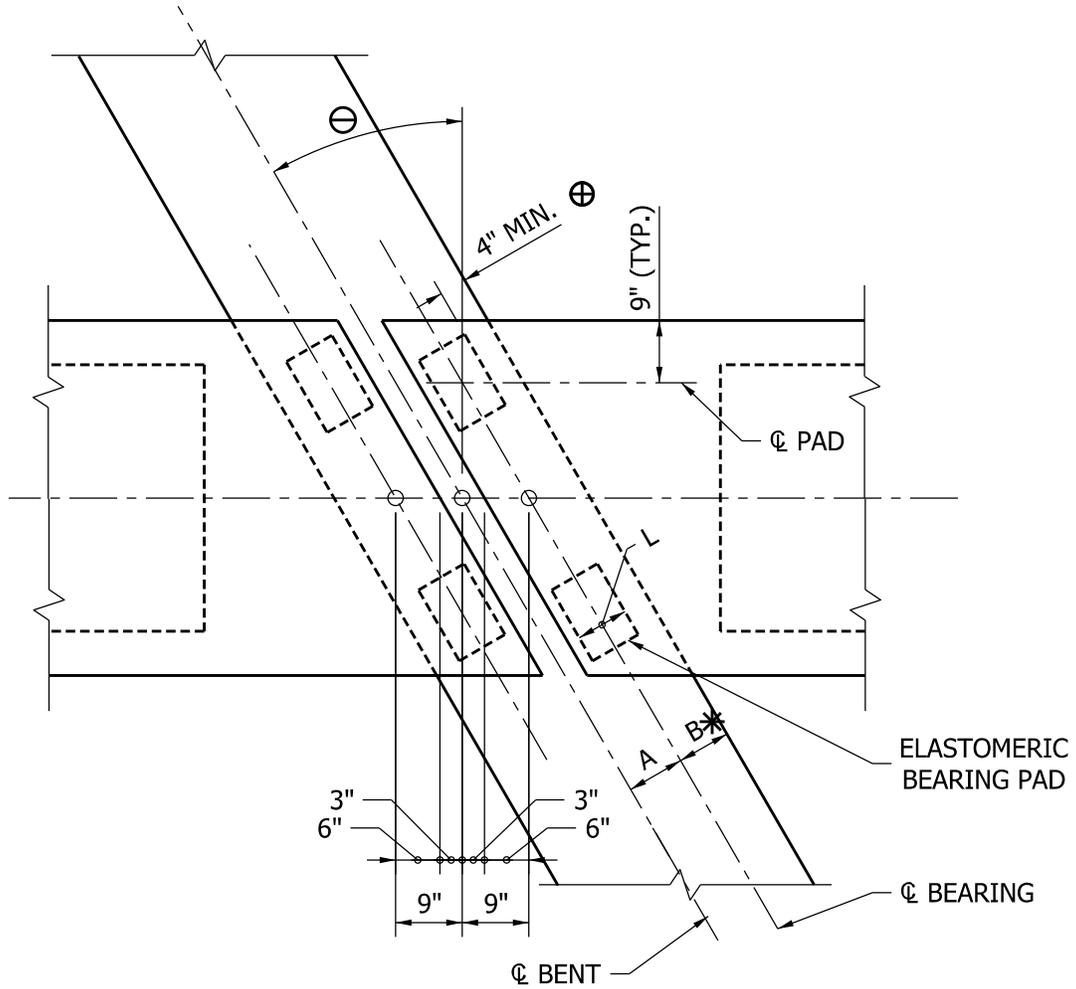
$$E = B - 0.5 D$$

$$F = E \sec \theta$$

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊗ CHECK SEISMIC MINIMUM SUPPORT LENGTH FOR EXPANSION BENT.

BOX BEAM: END BENT CAP SIZING AND BEARING LAYOUT DETAILS

Figure 406-16S

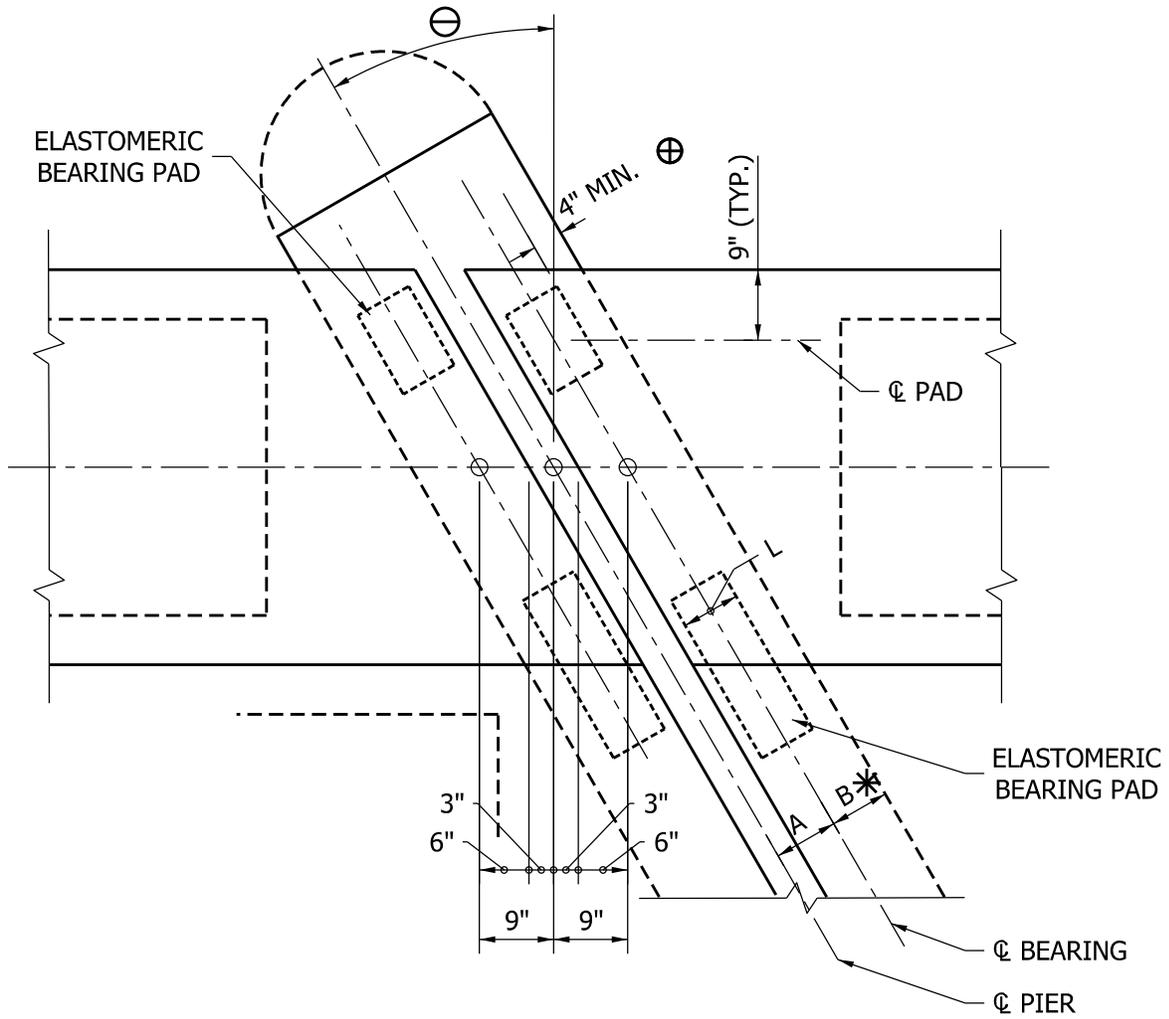


$A = 9'' \cos \Theta$
 $B = 0.5L + 4''$
 $CAP \ WIDTH = 2AB$
 $ACUTAL \ B = 1/2 \ CAP \ WIDTH - A$

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊕ USE 0.5 ft. FOR PIER BELOW EXPANSION JOINT.

BOX BEAM: PIER CAP SIZING AND BEARING LAYOUT DETAILS FOR SPREAD BEAMS

Figure 406-16T

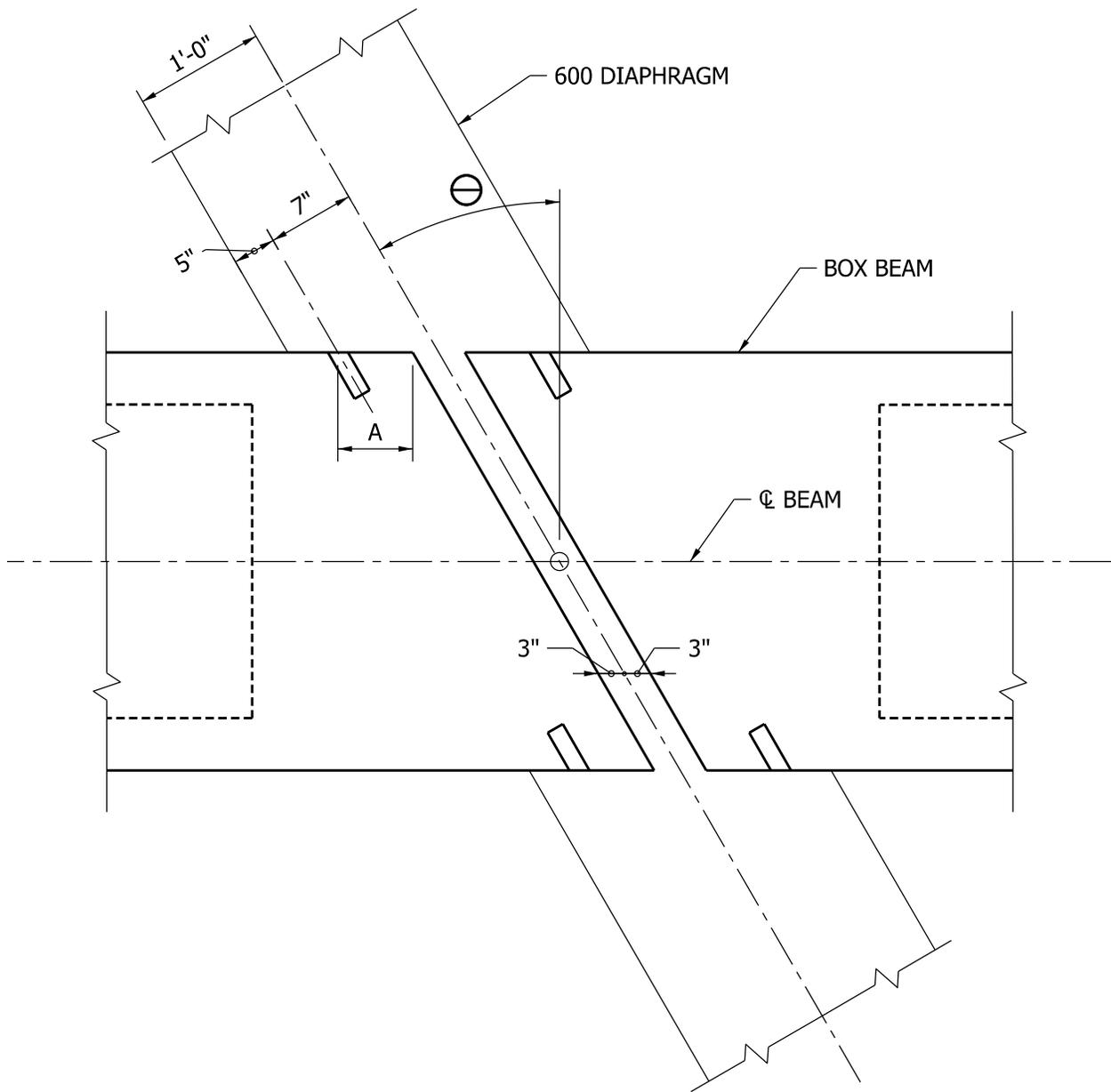


$A = 9'' \cos \Theta$
 $B = 0.5 L + 4''$
 CAP WIDTH = 2AB
 ACTUAL B = 1/2 CAP WIDTH - A

- * USE FOR SIZING CAP ONLY. ROUND UP TO AN INCREMENT OF 3"
- ⊕ USE 0.5 ft. FOR PIER BELOW EXPANSION JOINT

BOX BEAM: PIER CAP SIZING AND BEARING LAYOUT

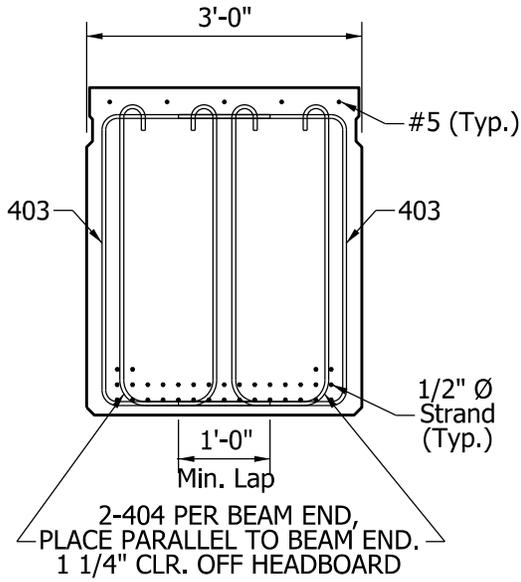
Figure 406-16U



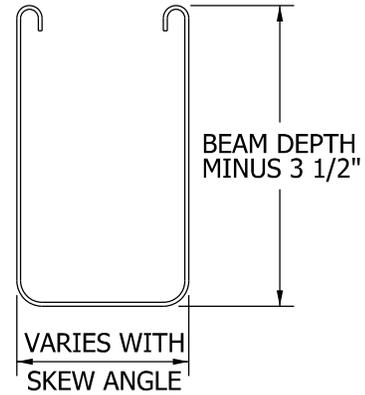
$$A = (7" / \cos \Theta) - 3" = \underline{\hspace{2cm}}$$

BOX BEAM INSERTS AT PIER DIAPHRAGM

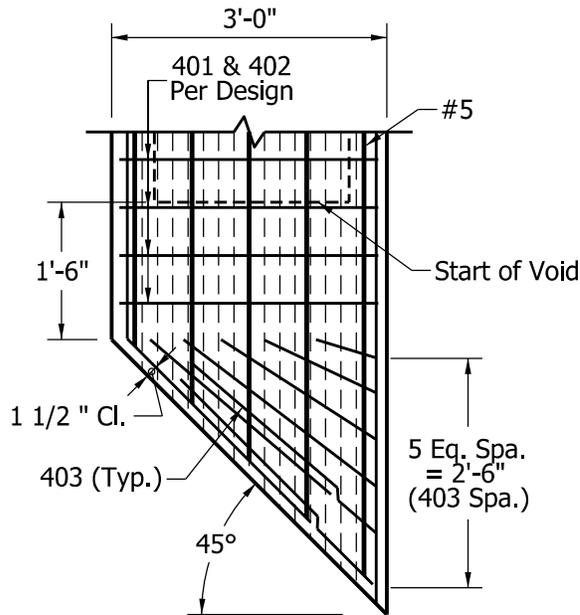
Figure 406-16V



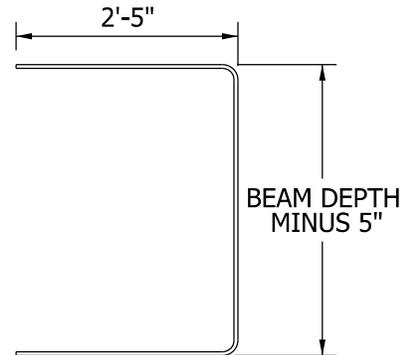
TYPICAL END REINFORCEMENT SECTION



404 BAR



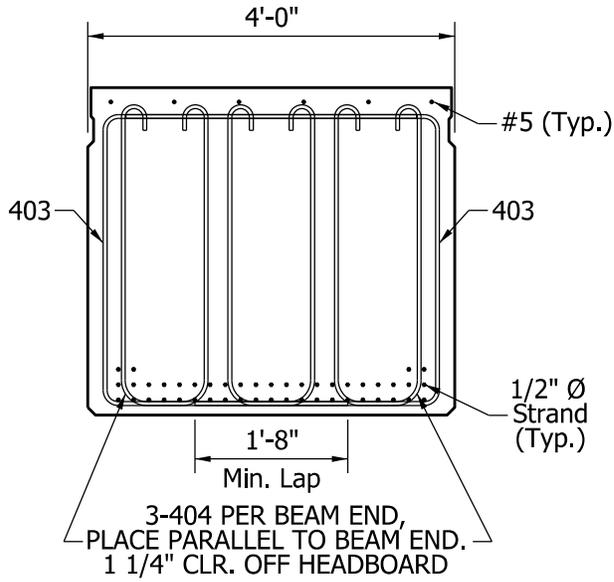
TYPICAL END REINFORCEMENT PLAN



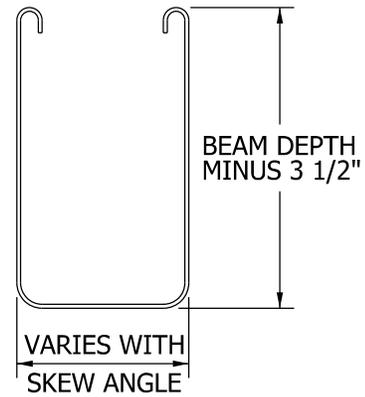
403 BAR

MILD REINFORCEMENT FOR 36 WIDTH SKEWED-BEAM END (45-deg Skew Shown)

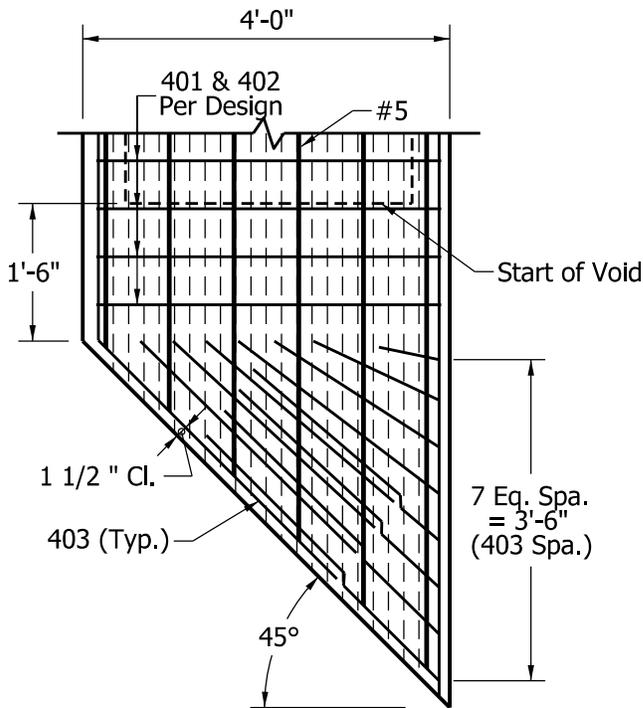
Figure 406-16W



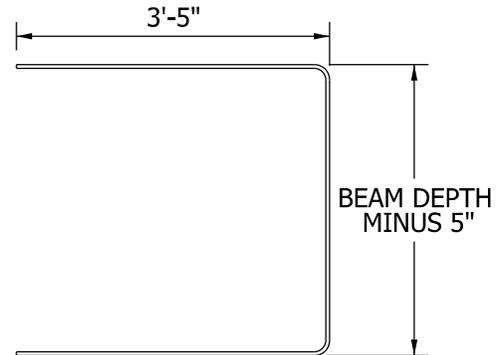
TYPICAL END REINFORCEMENT SECTION



404 BAR



TYPICAL END REINFORCEMENT PLAN



403 BAR

**MILD REINFORCEMENT FOR 48 WIDTH
SKEWED-BEAM END (45-deg Skew Shown)**

Figure 406-16X