



FABRICATION OF PRESTRESSED CONCRETE BRIDGE BEAMS

This article describes the process for fabricating prestressed concrete bridge beams. It also describes requirements for design, materials, handling, erection and quality. MDOT Standard Specifications For Construction (1990) and the "Special Provision For Prestressed Concrete" (SP5.05(A)) are the Department's primary specifications for prestressed concrete bridge beams.

In prestressing, "pre" indicates an earlier or prior time and "stressing" indicates subjection to stress or strain. Prestressing introduces internal stresses into a material to counteract stresses to be applied from an external force at a later time. In prestressed concrete beams, the internal stressing is applied by stretching steel strands and casting concrete around the strands. The concrete then hardens and bonds to the strands holding them in a stretched position. The strands are cut loose or detensioned after the concrete has sufficiently hardened. The bond between the concrete and the strands prevents them from returning to their original length, and the stress in the strands is transferred to the concrete, introducing internal stress into the member. These internal stresses are locked in the member to counteract externally applied loadings.

Development of prestressed concrete products began in the early 1940s. Philadelphia's Walnut Lane Bridge was the first prestressed concrete bridge constructed in the United States in 1950, using prestressed concrete I-beams. Michigan's first prestressed concrete bridge was constructed in the late 1950s. Since then, thousands of prestressed concrete bridge structures have been constructed. Now prestressed concrete is the preferred material for bridge beam applications due to its competitive initial cost and low maintenance characteristics.

Design of Beams

Box and I-Beam design (Fig. 1) are the two most popular types of prestressed concrete bridge beams today. The design span length of prestressed concrete bridge beams is limited by depth of section, concrete strength, and weight. Spans up to 136 feet in length are being used in Michigan, making prestressed concrete bridge beams very competitive with structural steel bridge beams. In addition prestressed beams cost much less to maintain than painted structural steel beams.

Design of box beams typically includes a void or block out in the middle of the cross-section to help reduce weight. The top and bottom sections carry most of the compressive and tensile stresses, while the two web sections (vertical members) of the box beam carry the shear stresses. I-beam design is geometrically quite different from box beam design. However, stresses developed in the flange and web sections of I-beams are similar to those developed in box beams.

All prestressed concrete bridge beams have reinforcing steel running longitudinally the full length of the beam and vertically. Longitudinal reinforcing steel prevents transverse shrinkage cracking during concrete casting and curing, and it also controls cracking in the top flange prior to casting the concrete bridge deck. Vertical reinforcing steel prevents excessive shear cracks in the beam. Placement of vertical reinforcing steel is closer together at the end of the beam where shear stress is maximum, and farther apart toward the center where shear stress is minimal. By tying longitudinal and vertical

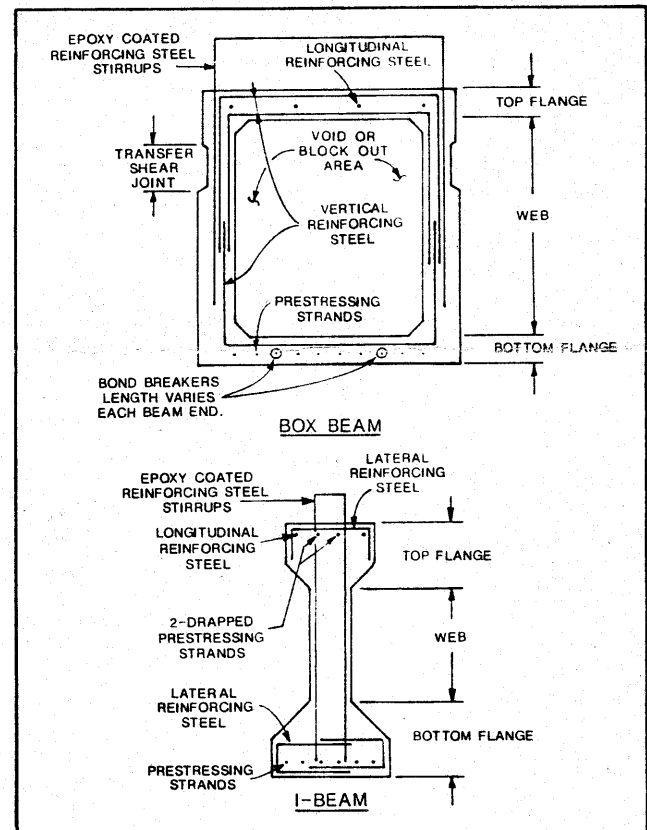


FIGURE 1

reinforcing steels together, they act better as a unit for placement during fabrication. In addition, the reinforcing steel in these beams is essential to prevent cracking during handling, shipping, erection, and subsequent service.

Prestressing strands provide the internal stressing force on the concrete beam. There may be as many as 50 strands per beam, depending on design requirements. These strands are placed in rows stacked in the bottom flange of the beam. The strands provide enough force in the beam to pull the entire beam into compression (both top and bottom flange). Once in service, the top flange remains compressed while the bottom flange develops slight tension whenever a maximum-load truck moves across the bridge. Bond breakers (plastic tubes slipped over the strands) at the beam ends help relieve compressive stress in the bottom of the beam that results from the strands being released or cut at each end. Draped strands running from the top flange at the beam ends to the bottom flange in the middle section provide the same stress-relief effect as bond breakers and eliminate the number of bond breakers required in the bottom flange. These draped strands also accommodate some of the shear stress in the beam. I-Beams are the only type of beams that can accommodate draped strands. The hollow center design of box beams prevents draped strand usage.

Casting Beds

Most fabrication facilities have three or four casting beds up to 350 feet long, but some casting beds are as long as 650 feet. On each bed,

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multiple beams can be fabricated end-to-end simultaneously. For example, on a 300 foot casting bed the fabricator can construct two 136 foot I-beams or nine 30 foot I-beams simultaneously. Each casting bed has end anchorages that maintain the tension force in the strands until the concrete has sufficient strength to absorb these forces by bond. Casting beds typically are constructed of steel, prestressed concrete or reinforced concrete. They usually are built slightly above the ground to avoid water damage during heavy rains and to accommodate steam pipes that run the full length of the bed for curing the beams after casting.

Casting beds have end anchorages provided by abutments usually supported by driving piles to depths required to resist overturning forces. End anchorages can also be provided by casting mass concrete (gravity type), abutments post-tensioned to a beam type bed or a compression strut type. End anchorages must sustain the tremendous forces of strand tensioning. Holes in the end anchorage plates permit the strands to pass through to the tensioning equipment installed beyond the end anchorage. End anchorage abutments have been known to pull completely out of the ground when too many strands are tensioned at once, exceeding the anchorage capacity.

Tensioning and Strands

There are two methods used to stress concrete (prestressing) prior to service loading:

Pretensioning involves pulling wire strands to a specified elongation before casting concrete around the strand. Cutting the strands occurs simultaneously and symmetrically at each end of the beam after the concrete has set and gained a specified strength. Cutting the strands causes them to try to recoil to their original length. The bond developed between the strands and concrete resists the strands' movement, causing the concrete to be placed in compression. This procedure is used almost exclusively by the Department for prestressing.

Post-tensioning requires properly positioned ducts to allow the strands to pass through when the concrete is cast and cured. Strand placement through ducts for tensioning occurs after the concrete has reached its proper strength. Pulling the strands into tension is achieved by anchoring one end and pulling the other end with a large jack. After jacking, the strand ends are secured or anchored at the ends and the hole filled with grout to help provide bond and protect the strands from corrosion. This was the procedure used on the Zilwaukee Bridge, both to post-tension the deck transversely and to post-tension the segments together longitudinally. Post-tensioning box beams are achieved in a similar manner by pulling beams together after erection, providing load transfer between beams by the friction developed on their side surfaces.

The Department requires all strands for prestressing to be ASTM A 416 Grade 270 low relaxation steel strands. These are 1/2 inch diameter strands composed of 7 stress-relieved wires. Strands typically are pulled to 75 percent of their breaking or ultimate strength, which is about 15 percent below the yield point for strands of this grade and type. Typical maximum tension force on one strand equals 31,000 lbs at time of bed tensioning. These high strength steel strands are very susceptible to damage prior to and during tensioning. During tensioning a nick or kink in a strand can cause failure. Failure of a damaged strand under tension is instantaneous and can cause great bodily harm and even death, as the tension energy is quickly released. Bodily harm is avoided by safe tensioning practice, which keeps the workers out of the line of the strands during tensioning.

Wedge-type strand chucks grip onto the strands during tensioning at each end anchorage abutment. Jacking devices provide a seating action between the strand chuck and the strand upon initial loading. Once the initial loading and seating is completed, final jacking commences to 31,000 lb. Jacking terminates once the required tension is in the strands, as measured by strand elongation.

Forms for Casting Concrete

Placement of steel forms for casting concrete commences after all the strand tensioning is complete. Bulkheads at the end of each beam are typically steel. Forms must be rigid and easily cleaned for reuse. Quick removal and assembly of forms allow beams cast one day to be removed the next morning; then the forms are cleaned, and new reinforcing steel installed. Next, strands are placed and tensioned, forms assembled, and new members cast in the afternoon. Form sizes are standardized for maximum interchangeability for standard I-beam and box beam designs. Placement of styrofoam boxes in the forms provide voids or block out spaces in box beams during casting. Placement of the styrofoam boxes occurs after casting the bottom flange, and are tied down to prevent movement.

Concrete Mixture

The Department's specifications make the design of the concrete mixture the responsibility of the prestressed beam fabricator, but the Department also lists very specific requirements for all materials used in the concrete mixture.

Cement can be either Type I or Type III. Most fabricators use a 7-sack Type III cement mixture. Type III cement is high-early strength cement, which achieves most of its strength in a concrete mixture in the first 24 hours. Achieving fast concrete strength allows fabricators to release or detension the strands within 12 to 20 hours and remove beams from casting beds in preparation for the next set of beams.

Coarse aggregate is specified as 6AA natural aggregate (usually crushed limestone), and must have a high freeze-thaw durability. Coarse aggregate used in prestressed concrete must be tested for freeze-thaw dilation and must not exceed a maximum dilation of 0.010 percent per 100 freeze-thaw cycles, equivalent to a freeze-thaw Durability Factor of 77. Fine aggregate must be 2NS sand. All sources for both coarse and fine aggregate must be tested and approved for use prior to the fabricator's incorporation of the material into prestressed concrete beams.

The other materials in the concrete are water and admixtures. The admixtures alter the behavior of the concrete mixture and enhance the performance of prestressed concrete. The four types of admixtures consist of air-entraining, water reducing, retarding, and corrosion inhibiting. Air-entraining admixture blends minute air voids into the mortar fraction of the concrete mixture preventing damage due to freezing and thawing; too much air causes a loss in strength of concrete without improving durability. Water-reducing admixtures, regular or superplasticizers (high-range water-reducers) provide additional workability to the concrete mixture by dispersing the cement grains, promoting greater flow, and decreasing the need for water. Reduction of water in the concrete mixture increases the strength. MDOT specifications permit higher slumps with use of water-reducers. Retarders help slow down the concrete mixture set time. Using Type III high-early strength cement causes the concrete mixture to set quickly, which gives little time for placing and finishing. (Retarders prolong the set time enough to allow time for casting long beams on long continuous beds.)

For more information on concrete admixtures see MATES article No. 5, March 1987.

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