Steel Forming of Precast, Prestressed Concrete I-Beams

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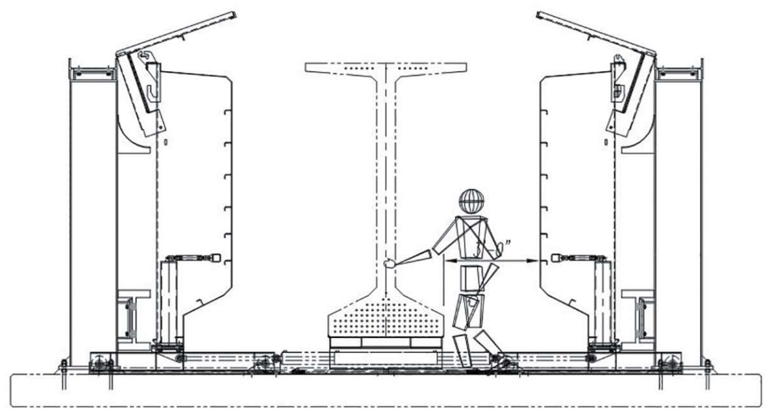
Precast, prestressed concrete I-beams are the most common girder shape used for bridges in the United States. They can span between 30 and 350 ft, the widest range of spans of any precast concrete girder stringer bridge product. The American Association of State Highway and Transportation Officials (AASHTO) I-beam series has been in use in the United States since it was adopted in 1957.[1]

More recent developments are given in the *PCI Bridge Design Manual*[2] and various state departments of transportation websites. Developments include the AASHTO-PCI bulb tee and the deck bulb tee in the 1980s, the Nebraska (NU) I-beam and the Washington State wide-flange girder in the 1990s, and a number of other state shapes in the 2000s and 2010s. As the shape of the I-beam evolves with time, general trends are observed.

The new shapes generally have a large bottom flange to allow for placement of more strands and thus an increase in span capacity. The top flange is generally wider and thinner than the original AASHTO beams, with flange width as large as 10 ft, to reduce or eliminate cast-in-place concrete deck forming and thus provide accelerated bridge construction. A number of owners are still using older shapes due to the capital investment involved in creating new forms and the corresponding modifications that might be necessary in the prestressing beds. Yet, another group of owners are seriously considering updating their shapes with new forms. In both cases, it is helpful to understand the features of forming and producing prestressed concrete I-beams. This understanding would help with the decisions needed to modify existing forms and the features desirable for acquiring new forms.



Example illustration of I-beam forms. Figure: Helser Industries.

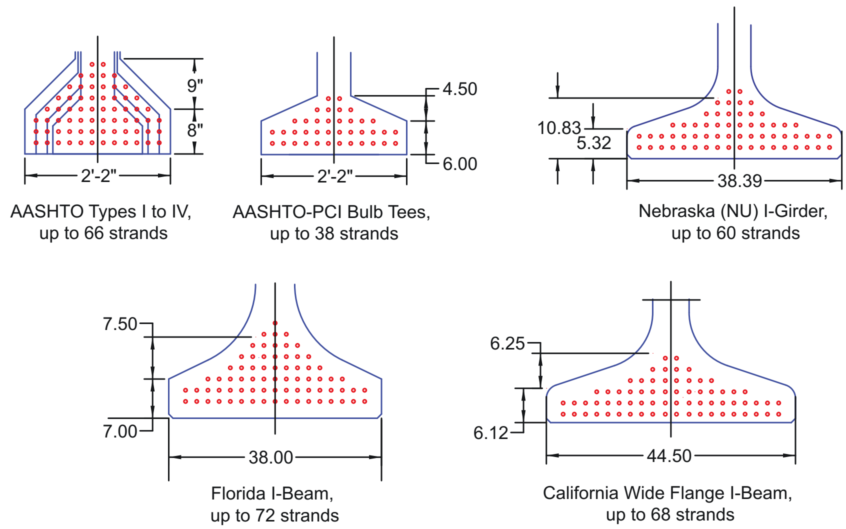
Two side-by-side beds with Nebraska (NU) beam forms. Note the stressing head in the foreground. Photo: e.Construct.USA LLC.

This article gives an overview of the historical development of I-beam shapes and the method used to produce I-beams. It discusses the desirable features in optimizing I-beam shapes. Finally, it presents options for possible modification of existing forms.

Understanding I-Beam Production

I-beams are often produced in prestressing beds that are 350 to 600 ft long. The forms are primarily two-sided forms that are moved in toward each other. They are tied at the bottom and at the top. At the bottom, a flat steel plate runs the full length of the bed. It forms the bottom face of the I-beam and is called the pallet. The pallet is elevated above the foundation to allow for tying of the side forms and for strand draping, if this option is utilized. The tops of the two side forms are tied together with ties at about 30 in. spacing, called the yokes.

Because the forms are continuous for the length of the bed, they are made of 40-ft-long sections that are bolted tightly together to ensure straightness for their full length



Bottom flange dimensions of selected I-beams. Note: All dimensions are in inches, unless marked otherwise. Figure: e.Construct.USA LLC.

and minimize the visibility of seams. The ends of each beam length are defined by steel or wood bulkheads that have holes to allow passage of the strands. Any special end reinforcement would require that additional holes be drilled in the bulkheads and would increase time and cost of production. The figure to the left shows a typical prestressing bed with the forms spaced out.

It is not desirable to have bars projecting from the concrete I-beam except at the top face, which is not formed and is expected to have composite action, or interface shear, reinforcement projecting from it.

The technology of forming for I-beams has evolved over the years to use hydraulics to move the forms and to react to demands for increasingly larger beams, which are nearing 10 ft in depth. The following sections illustrate the evolution of I-beam shapes, recommendations for future shapes, and, most importantly, the cost-effectiveness of various modification of existing forms to accommodate project needs

Evolution of I-Beam Shapes

Bottom Flange

The figure above shows the bottom flange dimensions for several types of I-beams. They are shown in a chronological order up to the most recent, which is the California I-beam that was introduced about 5 years ago. Also shown is the maximum number of strands that can be housed in the bottom flange.

Each shape corresponds to a series of beam sizes. For example, the AASHTO I-beams vary in depth from 28 to 54 in. Except for the early AASHTO shapes, the bottom flange dimensions are kept constant regardless of beam depth. The reason for keeping the bottom-flange dimensions constant is to simplify forming. The pallet over which the form is installed and that forms the bottom face (soffit) of the I-beam, is important for the design of the prestressing bed and the dimensions of the stressing head. It would be a significant capital expense to later increase it. It is also time-consuming to change pallets on a bed when changing beam types, so this is an added cost of production. Thus, it is preferable to keep it constant. Also, keeping the bottom flange geometry constant for the series of beams being considered would simplify forming for cast-in-place diaphragms, if needed.

Another observation is that the bottom flange size continues to increase with time. This development is the primary reason why I-beams recently have reached lengths of over 200 ft. At this time, the Florida I-beam has the largest bottom flange, which has a record length of 209 ft for a pretensioned I-beam.

It is possible to block out the outside edges of the bottom flange in order to create a smaller bottom flange, if necessary. However, this would be a modification that needs to be studied carefully. A narrower bottom flange is less stable during handling and shipping. The amount of concrete and weight saved may not justify the change in section and reinforcement details.

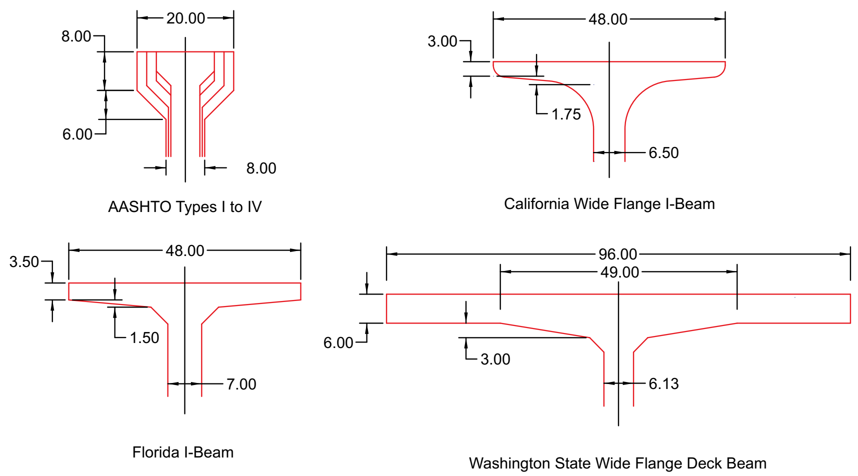
Web

The I-beam web is a significant part of the section area and beam weight. Using the smallest possible web width produces efficiencies, as long as there is room to place two layers of shear reinforcement on the two web faces with the minimum *AASHTO LRFD Bridge Design Specifications*-specified cover of 1 in. Shear strength is generally not a problem if enough shear reinforcement is placed. This is especially true since the adoption of the modified compression field theory in the AASHTO LRFD specifications. The AASHTO LRFD specifications allow as much shear stress as 0.25 f'_c in the web, which is nearly 250% of what had been allowed under the AASHTO *Standard Specifications for Highway Bridges* with a limit of $10\sqrt{f'_c}$.

In the early days of bridge I-beams, several states, such as Washington and Colorado, had I-beams with web widths of 5 in. However, these sections have largely been abandoned. Common widths are 6 in. (Nebraska and other states), 6.5 in. (California), and 7 in. (Florida and other states).

Reducing the web width for existing forms is a difficult process and would only serve the purpose of reducing the beam weight, which would not be recommended. Increasing the web width for the purpose of increasing shear capacity is seldom needed. However, it may be needed to allow a relatively shallow beam to span farther by creating more space for the pretensioning strands.

More commonly, the web width may have to be increased by 1 or 2 in. to allow for post-tensioning in addition to pretensioning. For example, Nebraska uses a 7-in. web width for I-beams with post-tensioning tendons containing up to fifteen 0.6-in.-diameter strands. California allows a web width of 8 in. with the same size tendon. As indicated earlier, the web is a significant part of the



Top flange dimensions of selected I-beams. Note: All dimensions are in inches, unless marked otherwise. Figure: e.Construct.USA LLC.

cross section. It significantly impacts the area and weight, but to a lesser extent the moment of inertia.

The most common way to increase the web width for existing forms is to space out the side forms by the required widening amount. This change requires modification of the set up at the bottom and at the top of the forms, and also a change in the bulkheads that define the end faces of the beam. At the bottom, steel spacers are provided. In the top, the "yoke," which holds the two side forms together and prevents spreading due to lateral pressure of the fresh concrete, is extended by the required web widening.

In most modern I-beam forms, it is allowed to have one set of bottom flange forms and one set of top flange forms for all beam depths. These two sets of forms add up to the depth of the shallowest beam in the series. For deeper beams, steel blocks are placed and bolted between the bottom and top flange forms. Alternatively, a separate set of the top forms is made for each of the beam depths in order to reduce the number of form parts, reduce the joint seams, and improve precision.

Top Flange

The top flange dimensions have varied considerably over the years. The figure above shows a sampling of top flanges of I-beams in use in the United States. The AASHTO Types I through IV represent old thinking, which is seldom used for newer products. The flanges are narrow and deep, and they change in size with the change in beam size.

Recently, the most popular flange width has been 48 in. and the flange is relatively thin. The flange needs to be adequate for resisting the fresh weight of the deck concrete, and it also helps stiffen the weak axis of the I-beam to allow for resistance to buckling during handling and shipping. This 4-ft width has been shown to be adequate for I-beams up to nearly 210 ft in length. After the deck concrete becomes composite with the I-beams, the value of the top flange in resisting subsequent loads diminishes. The deck becomes the "compression flange" of the beam/deck system in the positive moment zone of the span.

Integral precast concrete beams and decks have become more popular due to the desire for accelerated bridge construction, which lends itself to not having field-placed deck forms and cast-in-place concrete deck with the required labor and time for placement, finishing, and curing. An example of a deck beam is the recently introduced Washington State wide flange deck beam, the top flange of which is shown in the figure above. The bottom flange is similar to that of the Nebraska beam. A major disadvantage of a deck beam with a very wide top flange is the heavy weight. Thus, the system lends itself to relatively shallow depths with moderate piece lengths.

The value of having forms that will accommodate relatively wide flanges is the flexibility it offers. One of the simplest modifications that can be made on I-beam forms is to block out some of the top flange width with either wood or steel forming.

Summary

Precast, prestressed concrete I-beams are structurally efficient and popular for bridge applications. Bridge designers should be aware of the forms available in the vicinity of the bridge being designed. Costs and delays are caused by form modification, thus the decision to modify the beam shape should be based on the solution that produces the least time and cost for the project. It is most difficult to modify the bottom flange shape and least difficult to modify the top flange shape. The top-flange modification would involve placement of block-out forms to reduce the flange width.

Enlarging the section by making it wider is possible, however, the only feasible way to do this is to space the forms out by the necessary increase in form width. Such increase in width will have to be consistent for the full depth of the member including the flanges. If spacing out the side forms is desirable to increase member width, corresponding modification would be required for the pallet which forms the bottom face, the yokes that tie the two side forms together, and the bulkheads, which define the product length. These changes must be done in collaboration with the applicable precasters and their forming suppliers.

If an owner desires to create a new series of I-beams, the desirable features are a large bottom flange, a narrow web, and a wide top flange. This would allow for initial economy and future flexibility.

References:

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2. PCI. 2014. *PCI Bridge Design Manual*, 3rd Edition, 2nd Release, Chicago, IL: PCI.

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