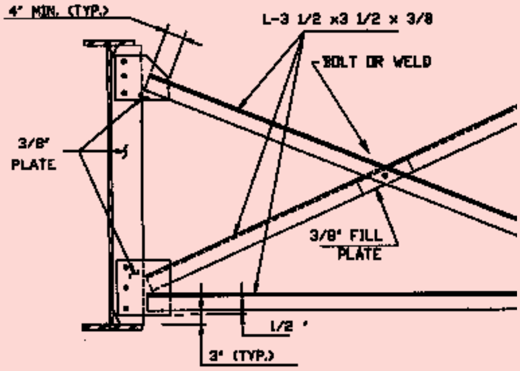

BRIDGE CROSSINGS

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Practical Information For The Bridge Industry

Why Steel Box Girders?

By Dann H. Hall

Bridge design utilizes the imaginative application of changing technology to meet changing demands. Steel box girders are widely acknowledged to be attractive but have been perceived to be more expensive than comparable I girders. Box girder design generally has required more labor than the design of comparable I girder bridges and computer analysis software has not been readily available. Some fabricators have not been anxious to undertake box girder fabrication.

Also, several large steel box girder bridges failed during construction in Europe during the 1960s. Steel box girders in the United States have been associated with metal fatigue in the webs due to box distortion near connection plate welds. Shipping limitations on the highway have eliminated the steel box girders form from consideration. Inspection of in situ box girders has been a problem when the box cross sections are too small for easy ingress. Given these issues, steel box girders have been slow to catch on as a viable form for a spectrum of bridge sites.

A steel box ramp in Seattle (photo courtesty of Parsons Brinkerhoff)

Since a bridge's primary purpose is to support loads, its structurally efficiency is its most important feature. However, there are other concomitant requirements placed on modern bridges: Functionality; serviceability; maintainability; aesthetic appeal and; buildability. After examining trade-offs that exist with regard to various forms meeting the sometimes paradoxical demands placed on modern bridges, the engineer chooses a bridge form. ***Increasingly, the steel box girder form is being chosen.***

Background

Straight welded steel box girders were first added to the AASHTO Standard Specifications for Highway Bridges in the early 1970s. Torsion is not included in these provisions. Instead, a formula providing wheel load factors for a limited number of boxes per traffic lane and limited spacing between webs is given such that torsion is believed to be negligible.

Two of the earliest curved steel box girder bridges in the United States were built in Massachusetts in the early 1960s. Welded box girders were selected to provide the torsional stiffness and strength necessary to satisfy a demanding horizontal radii of 150 feet.

Contemporaneously, a straight steel box girder bridge was designed to carry a railroad across the Missouri River at Kansas City. A steel box was selected to take advantage of the torsional stiffness that permitted the girders to be launched without additional bracing and to be placed in service quickly.

The Poplar Street Bridge, which carries I-70 across the Mississippi River at St. Louis, consists of dual bridges, each having an orthrotropic steel decks, each supported on twin steel box girders. Box sections were selected to provide stability of widely

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spaced girders of great span.

These earlier bridges utilized true steel boxes made with steel plates forming the four box sides, whereas the Atlanta Area Rapid Transit Authority (MARTA) design utilized single steel “tub” girders. “Tub” girders have webs and bottom flange of steel plates with separate steel top flanges attached to a composite concrete deck which completes the box. Again, the box shape provided the torsional stiffness to permit large deck overhangs so that a single box can carry two commuter trains side by side.

The AASHTO Guide Specifications for Horizontally Curved Bridges was introduced in 1980. These provisions require a rational analysis which must consider torsion. These specifications opened up new bridge forms, including the single box cross section and widely spaced boxes with large overhangs. For the first time, the design code recognized the torsional resistance of steel boxes; thus permitting the form to match that of the prestressed segmental concrete box girder bridge.

Aesthetics

As the highway system has become ubiquitous in nearly all cities, aesthetics has become increasingly important. A region’s residents and visitors often sense that the quality and appearance of the bridges reflect its style.

Decisions with respect to aesthetics can be divided into those relating to detail and those relating to form. Box girders can provide a smooth appearance because they hide bracing and stiffening while minimizing exposed steel surface. Thus, the engineer can design a detail-clean structure with few visible appurtenances.

Replacing pairs of I girders with a box girder does not change the essential form of the bridge. However, fewer boxes, with large deck overhangs, or at a minimum, a single box cross section, reveals the torsional effectiveness of the box. Torsional action can draw load to a central pier shaft rather than using expensive redundant pier columns to take loads straight down from the deck. This use of torsion to reduce the number of components exemplifies the inherent beauty of efficient structural form as proposed by David Billington in his book, The Bridge and the Tower.

Functionality

Functionality relates to traffic volume, speed and safety. Heavy traffic volume demands numerous grade separation structures. Increased speeds demand smoothly curved alignments with adequate visibility and setback of supports for safety.

Curved steel box girder bridges can provide long curved spans with fewer supports than would be required for segmented straight girder bridges.

Serviceability

Serviceability requires bridges to be rigid enough to prevent excessive vibration and deflection. Bridges must function without excessive repairs and minimal shut-downs during their design lives.

Limitation of deflections is the standard technique available to engineers to improve serviceability. Steel’s superior stiffness permits relatively shallow bridges. Box girders can provide an additional advantage in this regard to horizontal curves because the box acts as two I girders, thus heavier load characteristically applied to the outside girder of a curved I girder bridge is resisted by a box girder which has the flexural stiffness and strength of two I girders.

Fatigue caused by inadequate design and poor details can lead to cracking that can require expensive repairs. Internal cross bracing has caused fatigue distress in box girders when forces were not properly considered and a path provided to properly transmit cross frame forces to the girder flanges.

Maintainability

Maintainability relates to the ease and cost of maintenance over the life of the bridge. The bridge must be accessible for inspection and repairs without excessive disruptions to traffic and excessive cost.

The box configuration provides benefits with regard to maintenance through minimization of exposed bracing details and flanges that would otherwise collect debris that should be removed. Steel box girders have even been specified to eliminate roosting birds over pedestrian areas.

The elimination of exposed horizontal flange surfaces and bracing is especially beneficial for weathering steel applications when accumulation of debris which can hold moisture should be avoided. Repainting also is simplified when there is almost no bracing to be painted. Fewer boxes leads to fewer webs and they need paint on only one side.

Buildability

Bridges must be buildable with the existing technology and facilities with minimal disruption to the existing highway system and without unexpected delays and claims.

Bridge fabrication shops on navigable waterways in the much of the central and eastern U. S. have been shut. The Kansas City railroad bridge and the Popular Street bridge were fabricated in one of these now defunct shops and shipped by barge to the bridge site. The Interstate System provides an alternate means of transportation but box size is limited in weight, length and width.

To overcome shipping limitations, boxes can be

A steel box ramp near Miami

designed with a bolted seam along the bottom flange permitting halves of wide boxes to be shipped by highway or rail.

Modern fabrication equipment including computer controlled burning and drilling have made the welded steel box more economical to fabricate. Curved, haunched inclined webs are being faithfully burned from plates using torches driven by computers which have been fed data from the design drawings. Numeric controlled drilling permits the production of multiple bolt holes in near perfect location again with data from the design drawings.

Economy

Many of the items discussed above relate to the life-cost of a bridge. However, the initial cost is extremely important and certainly the most determinable. The total bridge cost, including the substructure cost, should be considered. Economical box bridges have a minimal number of girders and no more than one pier shaft per box. Since fabrication cost per pound of steel box girders is higher than for I girders, the box weight should be less than the weight of an equivalent I girder bridge.

American steel box girder designs generally use tub girders with inclined webs. Tub top flanges need less steel compared to a true box girder, and provide optimal support of the deck. The inclined webs provide a narrower, more efficient, bottom flange which permits reduction of steel in regions of low stress and a more compact flange for higher compressive strength which requires less stiffening. Tub girders are more practical with regard to welding inside compared to a closed box with its limited accessibility.

The use of single box cross sections for ramps is possible because the torsional stiffness permits large deck overhangs. The single box usually needs a single pier shaft with one or two bearings. Large deck overhangs and girder spacings usually require transverse post-tensioning (PT) with a vaulted deck. The savings in girder and substructure costs usually exceed any added deck cost.

The twin-steel box MacMillan Yard Bridge in Toronto, with a transversely PT vaulted concrete deck nearly 100’ wide successfully competed against a similar segmental concrete design. The numerous single box ramps used on the Boston Central Artery also have led to recent successes of steel box designs when competing with similar concrete designs. Earlier examples of single steel box ramps can be found near Miami and Seattle.

Box torsional stiffness permits longitudinal warping stresses to be all but ignored, whereas warping stresses demand significant increases in flange steel in horizontally curved I-girders.

No-nos

Since inspection of box girders is performed from inside the box, it is imperative that the boxes be easily accessible and that interior bracing be arranged for easy ingress. Box girders are not desirable for spans demanding box depths less than five feet.

Many closely spaced box girders are almost never economical. The fabrication cost is relatively constant per box regardless of its size so fewer is better. Too many boxes also leads to too many webs. The ratio of live-to-dead load is greater when boxes are closely spaced so fatigue is more likely to control the design.

Torsional stiffness of boxes causes problems with bridges when the supports are skewed. Since the girder cannot twist to conform to the supports, torsion may become excessive, so it is best to avoid sharply skewed boxes. Skews usually can be avoided by lengthening spans and shortening abutments or by the use of hammerhead piers or integral pier caps.

Overly wide compression flanges require expensive stiffening. The use of a haunched box girder combined with inclined webs produces narrower bottom flanges in the important negative moment regions. Another solution is the use of concrete acting compositely with the bottom compression flange. The concrete acts to stiffen the flange and to reduce the steel demand. Composite box flanges have been used in Europe and Canada and a project using this feature is being prepared in the United States for bid in 1997.

Torsional rigidity of curved steel boxes permits them to be shipped and erected without external bracing. Curved steel box girders have been launched successfully in Canada and there are plans to launch similar box girders in the United States.

Conclusions

Competition between steel multi-box bridges and single-box bridges of any material is actually between competing forms rather than between materials—a competition that the multi-box form will rarely win. Only when box girder bridges have the same form, i.e., an equal number of boxes and pier columns, can there be true competition between the designs with respect to the different materials.

Steel box girders are certainly more visually appealing and require less maintenance than I girders. They are particularly appealing, economically, when horizontal curvature is sharp, or when a launched construction is desirable.

However, an ill-conceived box girder bridge is likely to be exceedingly expensive. For example, too many boxes demanding too complex a substructure will rarely yield an efficient design. But when properly conceived and detailed, the steel box girder form can bear efficient and beautiful bridges.

Macmillan Yard Bridge in Toronto

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The mission of The National Steel Bridge Alliance (NSBA), which was formed in 1995, is to enhance the art and science of the design and construction of steel bridges. Its activities include organizing meetings, conferences and national symposia, conducting the Prize Bridge Awards competition, supporting research, developing design aids, and providing assistance to bridge owners and designers. The NSBA membership includes representatives from all aspects of the steel bridge industry.