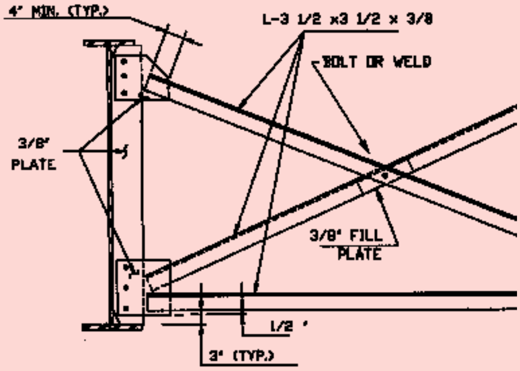


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# The Foundation of Great Steel Bridge Designs

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The foundation to any truly great steel bridge design includes a consistent and economical approach to both the superstructure and the substructure. Painstaking steps are often taken to "optimize" a steel superstructure design without due consideration given to the substructure design. Although the superstructure and substructure act in concert to form the structure, each is often analyzed for separate loads and isolated from the other as much as possible both physically and analytically. Substructure costs represent a significant portion of the total bridge cost. The form chosen for the substructure, often based on past experience or the desire to be conservative, may unknowingly lead to an inefficient steel design. The substructure form also has a marked effect on the aesthetic appeal of the structure. Certainly, the foundation of a great steel bridge design lies in a large part in the substructure.

To achieve a truly great steel design, the substructure and superstructure form must be compatible with respect to economic, structural and aesthetic demands. When alternate designs are prepared, the substructure for the steel design must be evaluated and designed concurrently with the superstructure. In addition, for cases where the chosen substructure form dictates the use of bearings, serious consideration should be given to the use of less expensive bearings — such as elastomeric bearings — for the steel alternate, especially for cases where the calculated movements and rotations are within the tolerable limits of these bearings.s.

The intent of this article is to present some basic ideas and concepts that may help lead to an improved foundation for great steel bridge designs.

## Form Follows Function

Bridge substructures are designed to safely transfer lateral loads as well as vertical loads. Some loads are applied directly to the substructure, but most loads are transferred to the substructure from the superstructure through the bearings or shear keys. While the superstructure generally must resist vertical loads far in excess of lateral loads, the substructure is subjected to a wide range of vertical load to lateral load effects. As a result, the form of the most efficient substructure must be deduced from its many functions, while remaining consistent with the existing soil conditions.

The vertical loads are primarily dead loads and vehicle live loads plus impact, and in some instances, seismic loads. Lateral loads include wind on the structure and on the live loads; live-load braking forces and centrifugal forces; friction forces in the bearings; thermal forces; ice, stream flow forces and earth pressure; ship impact forces; debris forces and seismic forces. Lateral loads cause overturning moments, which tend to cause uplift on one side of the foundation and an increased downward force on the opposite side.

The substructure is designed for various specified combinations of the resulting force effects, with either an increase in the allowable stress or else differing load factors applied to each force effect, to account for the reduced probability of the individual design forces occurring simultaneously.

Soil conditions often dictate the use of pile-supported foundations where the objective is to minimize the number of piles. The number of piles cannot be less than the number required to resist the full factored vertical load. Lateral loads create an increased downward force on some piles, but not an increase in the total vertical force. Therefore, if more piles are provided than are necessary to resist the vertical loads, it can be hypothesized that an improved substructure design may be possible. To minimize the number of piles, consideration should be given, where possible, to transferring the vertical loads from the superstructure to the ground through a single pier shaft. Single shaft piers are non-redundant, which eliminates the need to investigate multiple live-load positions to determine the maximum vertical live load on the pier. The smaller footprint of single shaft piers may also be advantageous in certain situations, such as when the use of a single shaft results in the elimination of a skewed pier.

The steel superstructure form supported on single shaft piers might consist of multiple girders supported on a hammerhead pier caps or a single box girder resting on top of the shafts. If clearance is an issue, the hammerhead pier caps can be designed to be integral with the girders. In some instances, integral pier caps can be used to eliminate skewed piers. Integral cap beams have been successfully constructed in this country using both reinforced and prestressed concrete, although steel cap beams are the most common. The cap beams have either been designed to rest on bearings or to be completely integral with the pier shaft.

Cap beams integral with the pier shafts have demonstrated a number of advantages on segmental concrete bridges that are designed to be fully integral with the pier shafts. Lateral loads (seismic forces, ship impact forces, etc.) can be distributed through the superstructure to the adjacent piers resulting in lower pier and foundation loads. Longitudinal forces — such as thermal and earthquake forces — may also be distributed to several piers, which can each resist the forces in double curvature thereby reducing the longitudinal moments at the base. Similar economies are indeed possible for steel bridges if a rationally determined degree of fixity is provided between the girders and the piers. With the development and application of economical details that provide a known degree of fixity, the behavior of a steel-girder bridge will be such that the superstructure and substructure act together as a more balanced structural system. In essence, the load paths can be tuned to provide overall economy in both the superstructure and the substructure to resist the lateral and longitudinal loads, and even the vertical loads (dead and vehicular live loads) as well. It is hoped that future study in this area will lead to the development of the necessary details and the confidence in the ability of these details to provide the desired degree of fixity for such load-path tuning.g.

The length of bridge that can be built without a joint is not defined by specification, but it has a significant effect on the cost of long viaduct-type bridges. Elimination of joints, in addition to providing savings in the number of bearings, diaphragms and expansion devices, removes simple supports, which tend to require spans that are shorter than the adjacent spans in order to provide the necessary economy. By attaching the superstructure to the pier with fixed bearings and letting the piers flex, less expensive elastomeric fixed bearings can be used and longitudinal forces can be distributed to several piers in proportion to their stiffnesses. Steel bridges over 2,000 feet in length have been successfully built in moderate to cold climates with expansion joints provided only at the ends.

For multiple column shafts, where there is more than one path for the vertical loads to reach the ground, the total vertical capacity of the substructure may be greater than the sum of the vertical loads. Thus, in this case, the substructure would be designed to resist more vertical load than is required. Although single shaft piers would be designed for less vertical load, if the shafts are made integral with the pier caps, longitudinal overturning moments would be transferred into the pier shaft. These moments would be the most critical when the concrete deck is cast on the superstructure, under certain live-load conditions when the loads are in one span only and under thermal forces. Lateral overturning moments would also be transferred to the shaft when the live loads are placed eccentrically on the deck and when horizontal curvature is present. Following conventional practice, the piles must be arranged in an optimal fashion to resist these moments.

The overturning moments due to the live loads could be reduced by using a broader cross section for the pier shaft. If large volumes of concrete are required in the pier shaft, the cost is increased and the casting rate may be limited by constraints imposed by heat of hydration dissipation. Instead, a hollow pier shaft may be desirable in this situation. Pier costs should be separated into reinforcement, concrete and forming costs, as a minimum. Simplicity and repetition of the formwork are the keys to economy. In some instances, it may be more economical to precast the shaft sections and ship them to the site where the sections can be prestressed together.

The preceding is simply one example of some of the thought processes that one might consider going through to arrive at a cost-effective substructure form to satisfy the demands of a particular steel bridge system. Obviously, each situation is unique and requires the development of its own thought processes and ideas. For example, for the case where a less costly spread footing might be applicable, the optimal arrangement of the cross section of the footing is less critical and other considerations might take precedence. The use of less costly spread footings would also generally permit the use of shorter spans.

## Span Optimization

Steel has the versatility to be utilized for most any span arrangement. However, in some competitive situations, steel has been compelled to use a particular span arrangement that has been optimized for the alternate design.

In a competitive situation, if spans have been optimized for the alternate design, the span arrangement for the steel design almost certainly will be different and must also be optimized. In many instances, the resulting optimum span arrangement for a steel design will differ from the optimum span arrangement for a concrete design.

For multiple continuous-span steel bridges, span lengths should preferably be arranged to yield approximately equal maximum positive dead-load moments in the end and center spans. These balanced span arrangements (end spans approximately 0.8 of the length of the center span) result in the largest possible negative moments at the adjacent piers, along with smaller concomitant positive moments and girder deflections. As a result, the optimum depth of the girder in all spans will be nearly the same resulting in a much more efficient design.

To illustrate this concept further, the unfactored moments in a tangent three-span continuous box girder caused by the dead load applied to the noncomposite section () are shown in Figure 1. The span arrangement for this girder (190'-0"–236'-0"–190'-0") is reasonably balanced.

Also shown in Figure 1 are the moments assuming the same total length for the box girder, but with a different span arrangement of 200'-0"–216'-0"–200'-0". For a steel-girder design, the uneven distribution of the moments from span to span — which is the case for both the dead and live load moments in this instance — will have a significant effect on the overall girder economy and efficiency. Assuming that the girder depth is optimized for the moments in the end spans, the chosen girder depth will be inefficient for the moments in the center span. Another disadvantage associated with the use of an unbalanced span arrangement for this particular design is the fact that the bottom-flange longitudinal stiffener in the box may not be able to be terminated at the field splices, as is the case for the balanced span arrangement. Thus, expensive termination details or lengthy extensions of the stiffener may have to be considered in order to satisfy fatigue requirements. Should longitudinal web stiffeners also be required, similar considerations would apply.

In situations where there are severe depth restrictions or where it is desirable to eliminate center piers (e.g. certain overpass-type structures), it may be desirable to provide short end spans. However, in cases where there are no such restrictions or needs, it will likely be more economical to extend the end spans to provide a balanced span ratio to avoid the costs associated with the possible need for tie-downs at the end bearings, inefficient girder depths, and additional moment in some spans. In curved structures, extension of the end spans may also permit the use of radial supports where skewed supports might have otherwise been necessary.

For major projects, superstructure and substructure cost curves should be developed for a series of preliminary designs using different span arrangements. Since the concrete deck costs are constant and independent of span length, they need not be considered when developing these curves. The optimum span arrangement lies at the minimum of the sum of the superstructure and substructure costs. These curves should always be regenerated to incorporate changes in unit costs that may result from an improved knowledge of specific site conditions.

## Integral Abutments

The use of integral abutments on steel bridges to eliminate roadway expansion joints and the associated bearings has been on the increase. In addition to reducing first costs and future maintenance costs, integral abutments may also provide for additional efficiencies in the overall substructure design.

In the case of fully integral abutments, the steel girders are encapsulated in capped-pile stub-type abutments, generally supported by a single row of piles, which provide the greatest flexibility and least resistance to cyclic thermal movements. Using these types of abutments, steel girder bridges up to about 400 ft in length can be constructed. To extend the span range for bridges without deck joints, some states utilize a semi-integral abutment concept, in which elastomeric bearings are typically introduced to provide a horizontal movable joint at the bridge seat to separate the superstructure from the abutment and allow freer rotation of the girders.

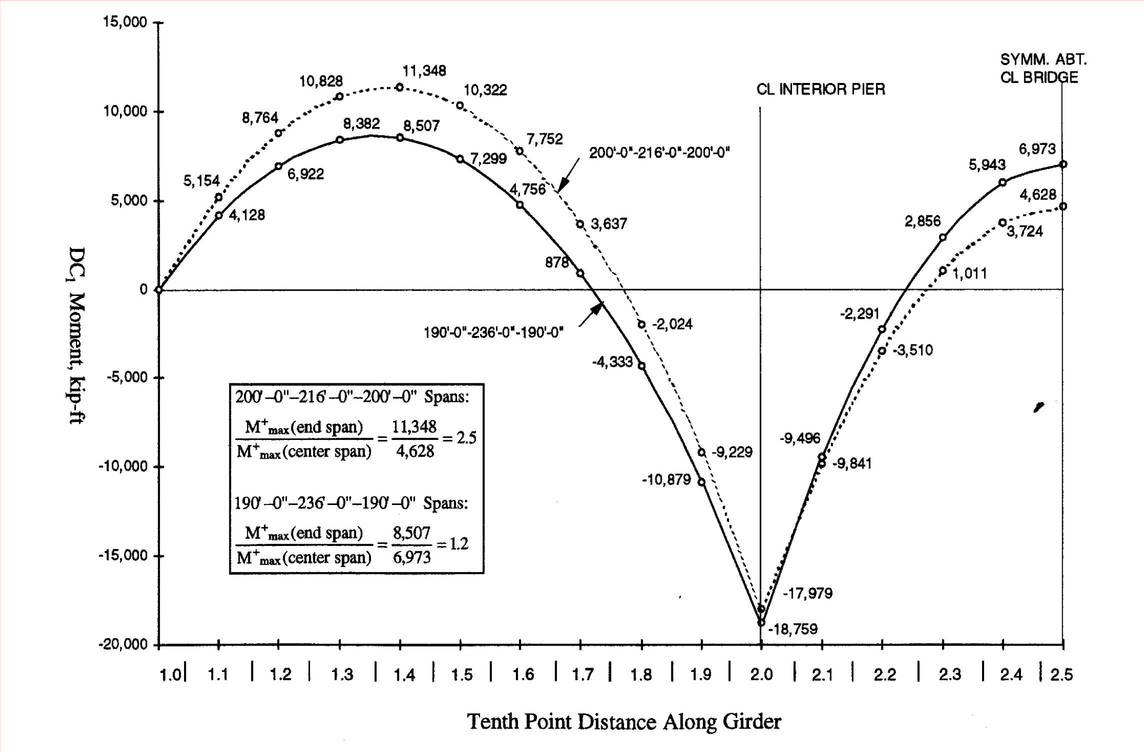


***Figure 1:*** *Component dead load (DC1) moments for different span arrangements box girder*

Additional details on the benefits, usage and design philosophies for integral abutments on steel bridges are available elsewhere. One such publication, entitled "Integral Abutments for Steel Bridges," prepared for the American Iron and Steel Institute by E.P. Wasserman and J.H. Walker of the Tennessee Department of Transportation, can be purchased from the National Steel Bridge Alliance by calling 800-644-2400. Two other publications of note by M.P. Burke of Burgess and Niple, Ltd. are "Integral Bridges", which is published in *Transportation Research Record 1275*, and "Semi-Integral Bridges: Movements and Forces", which is published in *Transportaton Research Record 1460*. Both of the preceding publications are available from the Transportation Research Board in Washington, DC by calling 202-334-3214.

## Closure

This article has briefly presented some general ideas and thoughts regarding the need for better overall integration of superstructure and substructure to arrive at more efficient and more competitive steel bridge systems. The need to develop the form of the superstructure and substructure in concert to most efficiently satisfy the structural and aesthetic demands has been discussed, along with the concepts of span optimization and integral abutments.

While many bridge designers have been cognizant of these concepts, they do not always apply them in ingenious ways. Steel is an inherently versatile material and it can be adapted to most any substructure and span arrangement. When the site dictates difficult span arrangements and pier designs, steel is often the only material of choice. However, its efficiency often suffers when designed to conform to foundations developed for other materials.

The foundation of a good steel bridge design lies in a holistic approach that encompasses the site demands, aesthetics and economics. Substructures are a major factor in all three aspects of this triad. A truly great steel bridge design is, therefore, one that needs no compromise in providing a sound foundation to adeqately satisfy this triad.

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