PRESTRESSED COMPOSITE BRIDGES WITH HIGH-PERFORMANCE CONCRETE DECKS AND HIGH-PERFORMANCE STEEL CORRUGATED WEBS

Mostafa A. Hassanain, Ph.D., P.Eng.

Edwards and Kelcey, Inc., Minneapolis, Minnesota

Research Objectives

Introduction: A recent report issued by the American Society of Civil Engineers about the state of America's infrastructure has indicated that almost 30% of the nation's bridges are structurally deficient or functionally obsolete.[1] High-performance concrete (HPC) and high-performance steel (HPS) can play a major role in the renewal of America's bridges. The development of these enhanced materials in and of itself will not be sufficient. There will have to be new structural systems developed to take full advantage of these materials' superior performance.

An innovative structural system: One possible structural system that combines both HPC and HPS has the potential to improve bridge performance, constructibility, aesthetics, and economy. The system consists of an externally prestressed box-girder having top and bottom HPC slabs connected by thin HPS corrugated webs. Several bridges utilizing this system have been built in France, Sweden, and Japan since 1986. Figure 1 shows the cross section of one of these bridges in Cognac, France.[2] A possible typical cross section of a corrugated web is shown in Figure 2.[2]

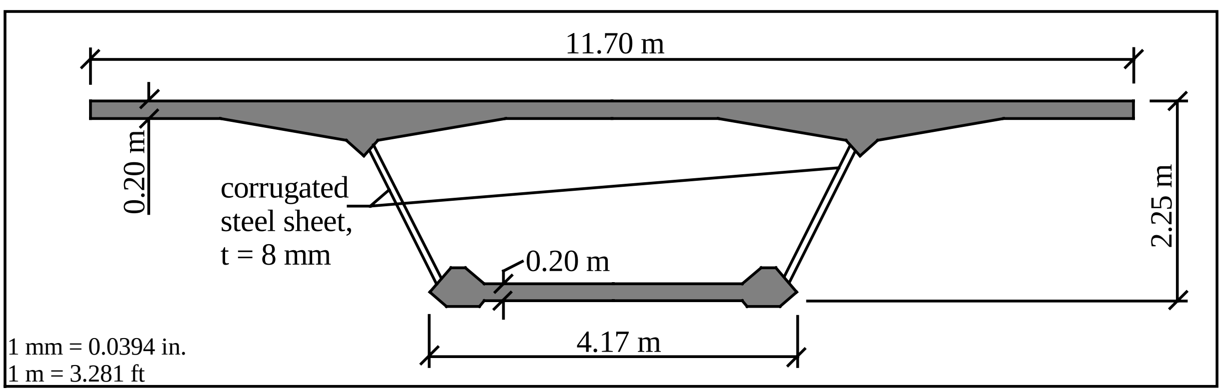

Figure 1. Bridge at Cognac, France - Typical mid-span section.

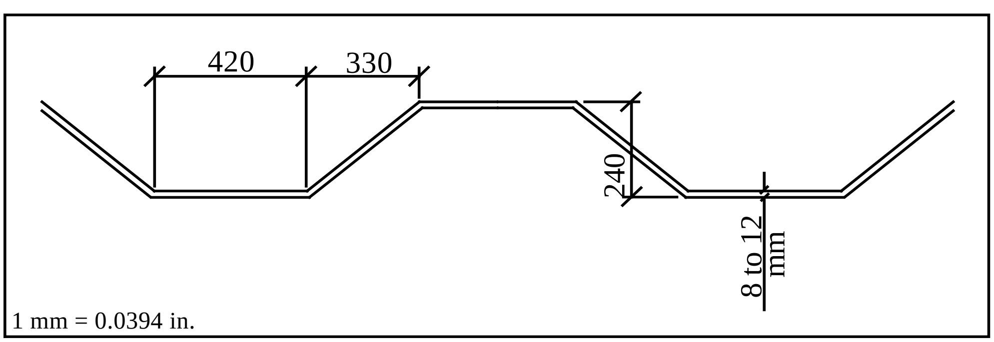

Figure 2. A possible typical section of a corrugated web.

Several researchers have discussed the advantages of corrugated steel webs over concrete webs and plane steel webs.[2-4] One of the most obvious advantages is that corrugated webs allow a reduction in the self-weight of the superstructure, and thereby help achieve longer spans and permit savings in incremental launching equipment costs. Additionally, in this system, the right material is used in the right place: HPC sustains bending moments and provides a durable deck, while HPS webs carry shear forces. The corrugations give the webs higher transverse stiffness to resist buckling under vertical loads, and allow the webs to compress easily under longitudinal loads. This compression ensures that prestressing forces in the concrete deck are not dissipated unnecessarily in the steel, and thus fewer tendons are needed as well as fewer shear connectors.

Research needs: Recent experimental and analytical research programs[4-7] have paved the way towards the development of design guidelines for girders with corrugated webs that could eventually be incorporated in AASHTO specifications for bridges. Several aspects, however, still need to be addressed in order to fully understand the behavior of this structural system. Two areas of concern are the stability (or instability) of the corrugated webs, and their resistance to fatigue when they are welded and/or spliced. Another area of interest concerns the problems of large-scale fabrication using webs likely to be as thin as 8 mm (5/16 in.).[8] In addition, detailed life cycle cost effectiveness studies are needed to verify the economic merits of this new system. It is unlikely that this bridge system will gain wide acceptance in the U.S. without a clear economic incentive. This study is intended to help provide such an incentive. The overall objective of the study is to assess the potential economic benefits from the utilization of HPC and HPS in the design and construction of this new composite system, and to compare the economic aspects of this system to the other commonly used types of prestressed concrete bridges.

Research Approach

The problem is formulated as an optimal design problem. Such a formulation transforms the laborious and time-consuming trial and error design process into a more rigorous and systematic procedure. The designer must identify a set of design variables that describe the structure, an objective function that measures the merits of alternate designs, and design constraints that must be satisfied. The objective function and the constraints must be functions of the design variables.

Once the optimal design problem has been formulated, it is transcribed into the following standard design optimization mathematical model: Find the set of n design variables contained in the vector $\{b\}$ that will minimize the objective function $f(\{b\}) = f(b_1, b_2, \ldots, b_n)$ subject to a set of k equality constraints $h_i(\{b\}) = 0$ with $i = 1, \ldots, k$; a set of m inequality constraints $g_i(\{b\}) \leq 0$ with $i = 1, \ldots, m$; and a set of lower and upper bounds on the ith design variable $b_i^l \leq b_i \leq b_i^u$, with $i = 1, \ldots, n$.

For the structural system under consideration, design variables include the cross-sectional dimensions of the top and bottom flanges, the required amounts of prestressing and non-prestressing flexural reinforcement, the corrugated web thickness, and the concrete compressive strength. The objective function is taken as the minimum superstructure cost. The design constraints are those imposed by design codes and those obtained from the literature.[5-7] The problem is highly nonlinear because both the objective function as well as most of the constraints are nonlinear functions of the design variables. Many numerical methods have been developed to solve nonlinear optimization problems. Many of these methods have been incorporated into general-purpose design optimization software packages. One such package is used in this study to solve the nonlinear optimal design problem using the mathematical model described above.

Expected Products

The optimization study will produce a set of design charts that could be used for the preliminary design of prestressed composite bridges with HPC decks and HPS corrugated webs. Sensitivity analyses of the obtained results with respect to the major assumptions made when formulating the problem will be performed to ensure that the findings of this study are applicable to a wide range of practical values surrounding those assumed.

Comparisons will be made between the cost effectiveness of this new composite structural system and that of other commonly used types of prestressed concrete bridges (e.g., slab-on-girder bridges and conventional box-girder bridges). The total cost of a prestressed composite bridge with corrugated webs is expected not to be dramatically different from the cost of a conventional prestressed concrete box-girder bridge, since the higher cost of the steel webs is balanced by the lower costs of concrete, prestressing and non-prestressing reinforcement. Construction is unlikely to involve particular costs, as savings in equipment balance the risks of inexperience. It is expected that the cost effectiveness of this new structural system will compare favorably with that of the other types of bridges, particularly for the longer span bridges.

Preliminary Results

The author has previously studied the economic benefits from the use of HPC for slab-on-girder highway bridges.[9] Figure 3 shows some of the results from that study.[9] The figure depicts cost curves that can be used to determine the optimal number and depth of I-girders in a bridge given the span length and the strength of the girder concrete. The girders utilized in that study are commonly used in Canada, and are comparable in their properties to AASHTO I-girders. Figure 3 can be used along with other cost curves developed for conventional box-girder bridges in comparison to cost curves developed for corrugated web composite bridges in order to determine the minimum cost superstructure system for a given span length. It is expected that the final results of this study should help provide the incentive for state departments of transportation to consider prestressed composite bridges with corrugated webs as a viable and cost effective alternative to some of the currently used bridge systems.

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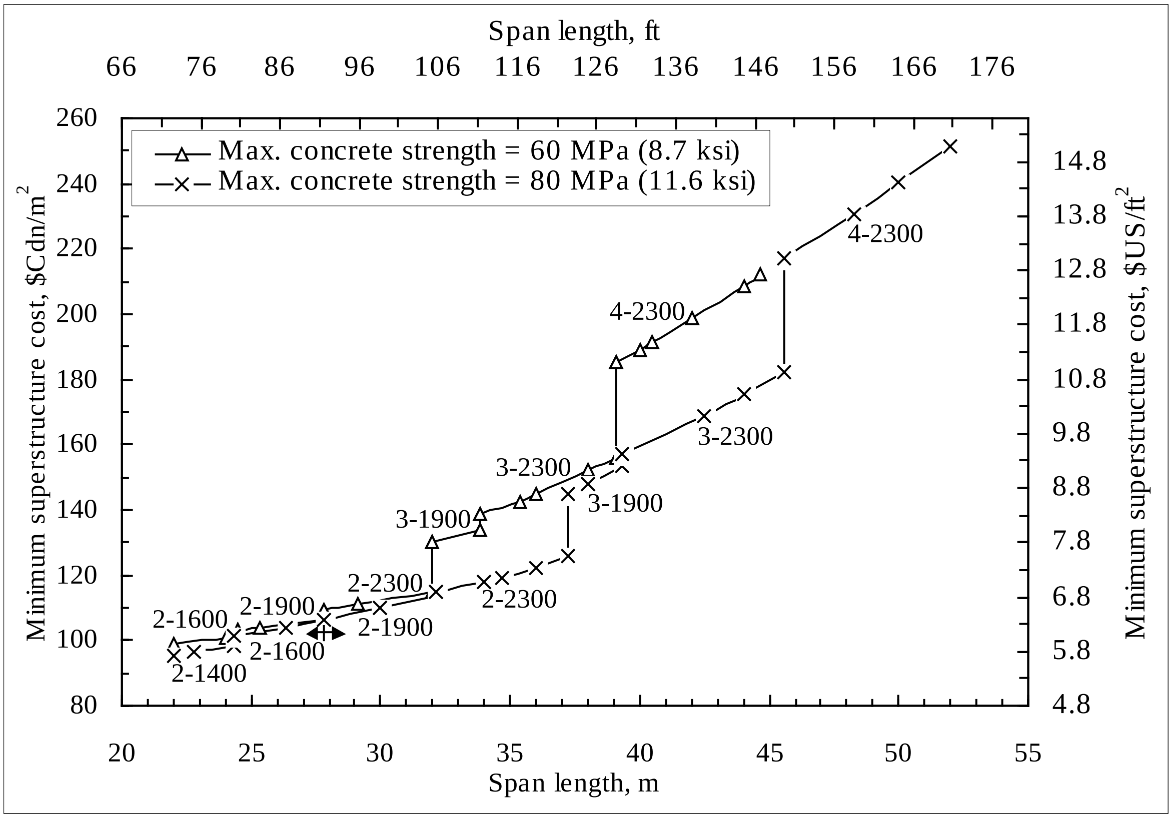

Figure 3. Cost curves for maximum I-girder concrete strengths of 60 and 80 MPa.

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