Modern Bridge Construction and Engineering Services

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In fiscal year 1988 the Federal Highway Administration (FHWA) apportionment for bridge replacement and rehabilitation amounted to $1.4 billion, which, when combined with local and state funds, makes up the $3 billion per year industry in bridge design and construction in the United States. This level of expenditure on bridge design and construction represents a surge in bridge activity in the United States brought on by the aging of existing structures and increased traffic demands on the U.S. highway system.

From a global perspective the United States has been relatively slow in applying innovation now available mostly from European sources to bridge design and construction. As discussed later in this article, the demand for postwar reconstruction in Europe stimulated innovation and transformed European bridge design and construction practice. America, during the 1950s and 1960s, however, felt no comparable urgency. As a result, there has been a noticeable lag in innovation and the transfer of technology from Europe to the United States—and there are many opportunities for improvements in the efficiency of design and construction methods in the United States. It is crucial that suppliers and buyers of bridge design and construction services in the United States recognize that innovation is necessary and that the barriers to enriching daily practice with the new technology lie not in technology itself but in the limited roles and expectations that have become traditional to bridge designers, contractors, and owners.

In particular, in the United States a contractor building a bridge works under the supervision of the engineer responsible to the owner for compliance of the work with the contract documents and the design intent. This U.S. practice is not universal. In Europe, bridge work is usually handled using the design or build concept. Under this arrangement, the owner or agency specifies the project requirements and calls for bids for design and construction. This approach has the advantage of promoting innovation at all stages of design and construction by allowing the design engineer to consider both the type of structure most suited to the site as well as the cost and time of construction.

If U.S. bridge design and construction teams are going to innovate in analytical and construction techniques (or be more effective at adopting innovations that originate elsewhere), adjustments are needed in the ways that clients, legal counselors, insurance carriers, contractors, and engineers conduct their professional and business activities. Moreover, the engineering community, regulating agencies, government, and universities must reconsider their respective roles if the United States is to produce the required innovation. Finally, the local, state, and federal agencies that buy bridges have the responsibility of identifying and managing procurement procedures that promote the best bridge design and efficient construction.

It is worth examining the postwar experience in Europe—an experience that created substantial innovation in bridge design and construction—for lessons applicable to U.S. policy.

The European Experience

Europe's dominance in bridge engineering and construction emerged during reconstruction efforts after World War II, when hundreds of major structures had to be replaced rapidly under tough economic and industry conditions. Steel fabricators were not ready to roll structural steel for bridge applications, so, as concrete substituted for steel as the dominant material for bridge building, the combined design or build concept was adopted to encourage competition and reduce design and construction time.

The postwar European experience can be divided into two distinct historical decades, each with its own special character. In the 1950s, Ulrich Finsterwalder introduced cast-in-place, segmental balanced cantilever prestressed concrete construction, and the structures built between the introduction of this technology and 1962 have been generally labeled the first generation of modern bridge development.

In the 1950s, it was demonstrated that by using the "balanced cantilever" method of erection, precast or cast-in-place concrete segments could be joined together progressively on top of a pier to form half of a bridge span on each side of the pier. In similar fashion and simultaneously, concrete segments erected on another pier, opposite the first, could be used to close the center


Cable-stayed bridge.

span. This method of erection, used repetitively, created multispan bridges with very long center spans—as long as 750 ft (230 m). Balanced cantilever construction also offers the advantages of eliminating ground-supported formwork over deep valleys, navigable channels, and congested urban or industrial areas; minimal disturbance to the surrounding terrain, allowing overhead construction while maintaining traffic; and construction that could proceed regardless of weather conditions.

The design of balanced cantilever bridges is complex and involves construction procedures that require specialized casting and erection equipment. But because most European governmental contractual arrangements permit design and construction firms to work together to develop innovative and cost-saving bridge designs, the casting and erection equipment designs were, and still are, considered at the same time as cost or design proposals. Thus, joint ventures between design firms with engineering excellence and construction firms with experience and equipment encouraged the development of in-house engineering expertise by contractors.

In such an atmosphere of engineering competition, new, innovative designs and construction practices advanced rapidly. The state of the art of designing and constructing segmental prestressed concrete box girder bridges advanced in response to the need for more productivity in the construction of bridge structures. During the 1950s new prestressing systems and alternative methods for constructing segmental prestressed concrete bridges were developed, and design and construction procedures were refined. However, in the 1960s a major slowdown in the development of concrete bridge technology took place when some of the first structures built in the 1950s showed signs of distress. The Federal Republic of Germany took drastic measures banning several of the newly developed schemes.

Engineers, builders, and owners wanted to know what was happening, how to take care of the problems, and how to retrofit these distressed structures for service. Intensive investigations identified specific problem areas; and predictably, as in most technological developments, the problems occurred in areas where theoretical assumptions had substituted for factual experience. Time-dependent effects on concrete structures proved to be highly uncertain, with their true magnitude revealed only as the years passed. Furthermore, the newly introduced construction schemes overwhelmed existing analytical bookkeeping methods, which were both cumbersome and prone to computational errors.

For example, to mathematically simulate the construction and stress history of a balanced cantilever bridge, computations must be updated at each stage of construction to reflect changes in the structural behavior of the bridge. Every time a segment is added or a tendon is tensioned, the structural system must be reanalyzed. Moreover, time causes the concrete and prestress to creep, shrink, and relax. Furthermore, when the statical scheme changes or when two adjoining cantilevers are made continuous, stress redistribution takes place and must be recalculated. This redistribution is not only the effect of the staged sequence of construction but also of time-dependent effects that keep taking place in concrete and in prestressing steel long after construction ends.

In summary, the problem turned out to be a lack of understanding about time-dependent effects on concrete and prestressing steel. Repair procedures developed to restore the structural integrity of the distressed bridges also promulgated new and more conservative guidelines to regulate design and construction of bridges using this technology.

This major historical event clearly defines the transition to what has been called the second generation of modern bridges.

By the 1960s, long-span, segmental bridges had established their competitive position. The industry addressed the problems encountered in the first generation of bridges through more research and advanced computational methods. Also, contractors started allowing better plant quality control in concrete production, plus getting the benefit of reducing creep and shrinkage in the finished structure, by letting segments undergo their natural and unrestrained strain changes during storage in the casting yards before they were finally incorporated in the structure.

Construction methods advanced rapidly, and segmental bridges were used in a wide range of erection schemes. In addition to the balanced cantilever method, span-by-span, incremental launching, progressive placing, and various combinations or modifications of these basic schemes were used.

Also, cable-stayed bridges in steel and concrete became the solution for spans longer than 700 ft, the limit for girder bridges. They were developed as an extrapolation of the balanced cantilever scheme: the cables replaced the posttensioning tendons projecting outside the structure, causing a gain in moment capability because of the increased moment arm.

The development of cable-stayed bridges, inhibited at first by the analytical complexity and stay-cable fatigue, moved forward with developments in computer hardware and software and with developments in modern materials technology and advanced testing facilities.

Almost simultaneous with the development of the second generation of European bridges were major developments in segmental bridges and cable-stayed bridges taking place in South America, Canada, and Mexico. Today there are more segmental bridges in South America and Canada than in the United States, and more cable-stayed bridges in South America, Canada, and Mexico than in Europe. In South America, the demands for new roads to develop virgin areas and to solve traffic problems in the growing and congested urban areas have produced record bridge construction rates and started important trends. Construction on a modern cable-stayed bridge and the final product are shown in the photographs.

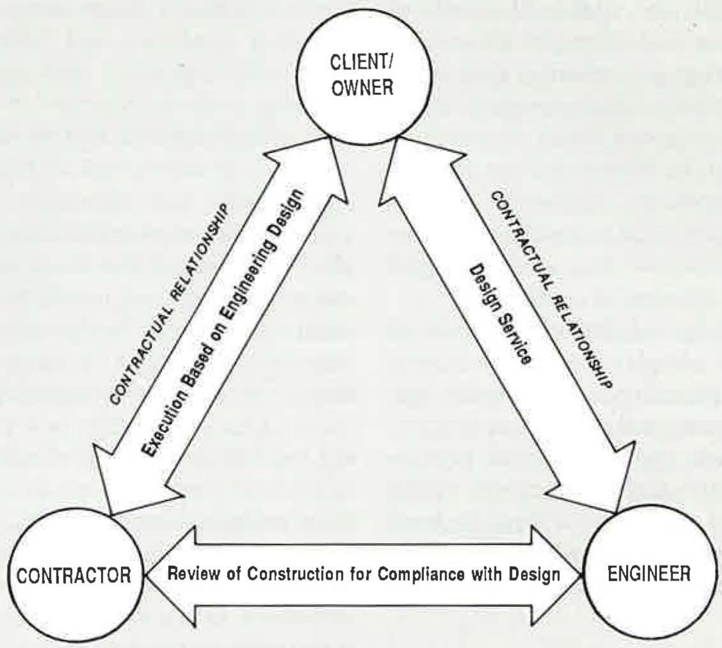

FIGURE 1 Functional relationship in a typical bridge project in U.S. practice.

The U.S. Experience

Based on recent bridge inventory and inspection programs, the United States has recognized the need to replace or to rehabilitate approximately 50 percent of the major bridges in the country. Funds for this work are being generated by new local and federal gasoline taxes, but the U.S. practice of bridge building has not advanced or incorporated the European formula, in which designers, contractors, and owner/agencies work together to meet the common objective of building bridges that are more time and cost efficient.

If we look back, it is clear that while major developments in European bridge technology were taking place, no similar efforts were under way in the United States. Not until the European market was saturated did the Europeans try to export their technology.

The major obstacle to ready acceptance of the European experience was the U.S. construction industry's structure, which clearly allotted the responsibilities and functions for design and for construction to two different services groups. Those in design services were not involved with contractors, and contractors in turn did not consider engineering functions part of their construction contract responsibilities. The process that could have combined the two functions, the design or build bidding approach, particularly in the field of bridge and highway work, was not their standard practice. The traditional structure of the U.S. bridge design and construction industry is illustrated in Figure 1.

The first bridges built in the United States based on the European experience were the Pine Valley Creek Bridge in California in 1969, using cast-in-place segmental construction with traveling forms, and the JFK Memorial Causeway Bridge, which opened to traffic in 1973. The precast segmental box girder for the JFK bridge was built in Corpus Christi, Texas, as a pilot project following a comprehensive model test program at the University of Texas at Austin. After concluding that the segmental bridge model safely carried the service and ultimate loads for all critical moment and shear loading configurations established by the analysis, a clean bill of health was given to proceed with actual construction. Moreover, theoretical calculations agreed with experimental results and actual construction.

After this major event took place, engineers, specialized material suppliers, and contractors saw the business opportunity and imported this technology when the economic conditions of the early 1970s demanded it. By the end of the 1970s, the FHWA issued a directive requiring competing, alternative designs for steel and concrete for any major bridges in the United States. This opened the doors for major changes in bridge technology.

Successful innovation came first in concrete bridge construction, followed by improvements in steel bridges. Small and new design firms rushed in to take control of the concrete bridge design market. To match the competitive success of concrete bridges, the steel industry had to offer free engineering to design firms to improve the analytical capabilities of the designers. In addition, the steel industry had to lobby extensively to modify the established design criteria and the controlling policies to pave the way for new design concepts in steel. Research and development also improved national applications for steel, including the improvement of site assembly by using steel erectors that duplicated the effective erection schemes of concrete segmental construction, as in the case of the Baytown Bridge (bid in 1986).

The design competition requirement on all federally funded long-span bridges (discussed in the next section) forced changes in material use by demanding plant control tolerances, for example, reducing field fabrication to a minimum, which improves quality, and stricter quality controls overall. Such requirements enabled both more and better construction control and improved fabrication techniques, and encouraged engineers and contractors to use more sophisticated analytical methods under more demanding quality control conditions.

Current Trends and Barriers

Two aspects of the procurement process for bridge design and construction are especially important to stimulating innovation in the U.S. bridge industry. First, current bridge design and construction procedures require that alternative steel and concrete designs compete on all major federally funded projects. This is more than a legal requirement—the "extra" design opportunity is a challenge to incorporate the innovative techniques that can give a competing design an important advantage in performance or constructibility. Second, after the design phase is completed, but before a bridge project begins, price competition among contractors drives innovation in the means and methods of construction, factors that can dramatically affect the price tag on a structure.

The alternative design requirement also means that the contractor has alternatives under redesign clauses in the bidding documents. These redesign clauses fall into two categories: (a) the construction options allowed within the general design and (b) more significant changes made according to the "value engineering" concept.

Required alternative designs are not new. In the 1950s, prestressed concrete structures had to be presented as alternatives to conventional designs. In 1978, the Federal Highway Administration issued a directive to encourage alternative design on all major bridges in an attempt to fight inflation and a then-current trend of bids coming in 5 percent over the engineer's estimate. The alternative design program in effect since then has produced very competitive bids, reversing the previous trend and producing more projects bid at or under the engineer's estimate. In the state of Florida the cost of major bridges in the 1980s has remained constant because of improved designs and construction schemes that offset the rising costs of materials and labor.

However, innovation in bridge design and construction has been sharply curtailed by legal and professional liability concerns spawned by the openness in the contract documents that allows contractors more flexibility. Liability concerns have also changed the nature of the relationship between the engineer and the contractor.

The future success of alternative designs will depend on the structuring of the contract documents to preserve the contractor's high degree of flexibility in those optional details and construction methods that do not modify the design intent. Contracts must also keep the responsibility and liability separate and under the two distinct categories of design intent and contractor ways and means. Properly structured contract documents must provide clarity without restricting freedom; that is, true performance specifications must preserve the basic design requirements without precluding further development within these requirements. Also, policy changes in the functions engineers perform must be adequately addressed.

The current policy as laid out in "Alternate Bridge Designs" prepared by the U.S. Department of Transportation FHWA Technical Advisory (T 5140.12) is a start, but many of the other lessons learned still need to be incorporated. Even though the closer relationship between design and construction activities has clearly established closer ties between engineers and contractors, two major issues continue to inhibit the acceptance of contractor alternative design or build proposals.

These two issues are the twin questions of who pays for design modifications and who takes ultimate responsibility for the design. In a traditional design relationship the owner backs up the engineer unless he or she is found to be negligent. On a contractor design or build alternative the owner does not want to co-sign on the design. In some instances, owners have taken the stand that if the contractor's alternative design will cost more than the client's or require modifications, then the contractor should abandon the alternative and build the client's design for the alternative bid price. From an insurance and legal point of view, this scenario has resulted in various claims, lawsuits, and increased professional liability premiums.

Antagonistic positions definitely do not help improve efficiency. Therefore, an effort to cooperate in defining mutually acceptable new standards will require a joint effort by the client's policymaking agencies, the construction industry, and design services groups. Clients must embrace better alternative design procedures to lift the barriers

continued on page 32