*A2C03: Committee on Concrete Bridges*
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# Concrete Bridges

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Concrete is the most-used construction material for bridges in the United States, and indeed in the world. The percentage of bridges built annually with the three major construction materials is illustrated in Figure 1.

The application of prestressing to bridges has grown rapidly and steadily, beginning in 1949 with high-strength steel wires in the Walnut Lane Bridge in Philadelphia, Pennsylvania. According to the Federal Highway Administration's 1994 National Bridge Inventory data, as shown in Figure 1, from 1950 to the early 1990s, prestressed concrete bridges have gone from being virtually nonexistent to representing over 50 percent of all bridges built in the United States.

Prestressing has also played an important role in extending the span capability of concrete bridges. By the late 1990s, spliced-girder spans reached a record 100 m (330 ft). Construction of segmental concrete bridges began in the United States in 1974. Currently, close to 200 segmental concrete bridges have been built or are under construction, with spans up to 240 m (800 ft).

Late in the 1970s, cable-stayed construction raised the bar for concrete bridges. By 1982, the Sunshine Skyway Bridge in Tampa, Florida, had set a new record for concrete bridges, with a main span of 365 m (1,200 ft). The next year, the Dames Point Bridge in Jacksonville, Florida, extended the record to 400 m (1,300 ft).

## HIGH-PERFORMANCE CONCRETE

### Compressive Strength

For many years the design of precast prestressed concrete girders was based on concrete compressive strengths of 34 to 41 MPa (5,000 to 6,000 psi). This strength level served the industry well and provided the basis for establishing the prestressed concrete bridge industry in the United States. In the 1990s the industry began to utilize higher concrete compressive strengths in design, and at the start of the new millennium the industry is poised to accept the use of concrete compressive strengths up to 70 MPa (10,000 psi).

For the future, the industry needs to seek ways to effectively utilize even higher concrete compressive strengths. The ready-mixed concrete industry has been producing concretes with compressive strengths in excess of 70 MPa for over 20 years. Several demonstration projects have illustrated that strengths above 70 MPa can be achieved for prestressed concrete girders. Barriers need to be removed to allow the greater use of these materials. At the same time, owners, designers, contractors, and fabricators need to be more receptive to the use of higher-compressive-strength concretes.

### Durability

High-performance concrete (HPC) can be specified as high compressive strength (e.g., in prestressed girders) or as conventional compressive strength with improved durability (e.g., in cast-in-place bridge decks and substructures). There is a need to develop a better understanding of all the parameters that affect durability, such as resistance to chemical, electrochemical, and environmental mechanisms that attack the integrity of the material. Significant differences might occur in the long-term durability of adjacent twin structures constructed at the same time using identical materials. This reveals our lack of understanding and control of the parameters that affect durability.

## NEW MATERIALS

Concrete design specifications have in the past focused primarily on the compressive strength. Concrete is slowly moving toward an engineered material whose direct performance can be altered by the designer. Material properties such as permeability, ductility, freeze-thaw resistance, durability, abrasion resistance, reactivity, and strength will be specified. The HPC initiative has gone a long way in promoting these specifications, but much more can be done. Additives, such a fibers or chemicals, can significantly alter the basic properties of concrete. Other new materials, such as fiber-reinforced polymer composites, nonmetallic reinforcement (glass fiber-reinforced and carbon fiber-reinforced plastic, etc.), new metallic reinforcements, or high-strength steel reinforcement can also be used to enhance the performance of what is considered to be a traditional material. Higher-strength reinforcement could be particularly useful when coupled with high-strength concrete. As our natural resources diminish, alternative aggregate sources (e.g., recycled aggregate) and further replacement of cementitious materials with recycled products are being examined. Highly reactive cements and reactive aggregates will be concerns of the past as new materials with long-term durability become commonplace.

New materials will also find increasing demand in repair and retrofitting. As the bridge inventory continues to get older, increasing the usable life of structures will become critical. Some innovative materials, although not economical for complete bridges, will find their niche in retrofit and repair.

## OPTIMIZED SECTIONS

In early applications of prestressed concrete to bridges, designers developed their own ideas of the best girder sections. The result is that each contractor used slightly different girder shapes. It was too expensive to design custom girders for each project.

As a result, representatives for the Bureau of Public Roads (now FHWA), the American Association of State Highway Officials (AASHO) (now AASHTO), and the Prestressed Concrete Institute (PCI) began work to standardize bridge girder sections. The AASHTO-PCI standard girder sections Types I through IV were developed in the late 1950s and Types V and VI in the early 1960s. There is no doubt that standardization of girders has simplified design, has led to wider utilization of prestressed concrete for bridges, and, more importantly, has led to reduction in cost.

With advancements in the technology of prestressed concrete design and construction, numerous states started to refine their designs and to develop their own standard sections. As a result, in the late 1970s, FHWA sponsored a study to evaluate existing standard girder sections and determine the most efficient girders. This study concluded that bulb-tees were the most efficient sections. These sections could lead to reduction in girder weights of up to 35 percent compared with the AASHTO Type VI and cost savings up to 17 percent compared with the AASHTO-PCI girders, for equal span capability. On the basis of the FHWA study, PCI developed the PCI bulb-tee standard, which was endorsed by bridge engineers at the 1987 AASHTO annual meeting. Subsequently, the PCI bulb-tee cross section was adopted in several states. In addition, similar cross sections were developed and adopted in Florida, Nebraska, and the New England states. These cross sections are also cost-effective with high-strength concretes for span lengths up to about 60 m (200 ft).

## SPLICED GIRDERS

Spliced concrete I-girder bridges are cost-effective for a span range of 35 to 90 m (120 to 300 ft). Other shapes besides I-girders include U, T, and rectangular girders, although the dominant shape in applications to date has been the I-girder, primarily because of its relatively low cost. A feature of spliced bridges is the flexibility they provide in selection of span length, number and locations of piers, segment lengths, and splice locations. Spliced girders have the ability to adapt to curved superstructure alignments by utilizing short segment lengths and accommodating the change in direction in the cast-in-place joints. Continuity in spliced girder bridges can be achieved through full-length posttensioning, conventional reinforcement in the deck, high-strength threaded bar splicing, or pretensioned strand splicing, although the great majority of applications utilize full-length posttensioning. The availability of concrete compressive strengths higher than the traditional 34 MPa (5,000 psi) significantly improves the economy of spliced girder designs, in which high flexural and shear stresses are concentrated near the piers. Development of standardized haunched girder pier segments is needed for efficiency in negative-moment zones. Currently, the segment shapes vary from a gradually thickening bottom flange to a curved haunch with constant-sized bottom flange and variable web depth.

## SEGMENTAL BRIDGES

Segmental concrete bridges have become an established type of construction for highway and transit projects on constrained sites. Typical applications include transit systems over existing urban streets and highways, reconstruction of existing interchanges and bridges under traffic, or projects that cross environmentally sensitive sites. In addition, segmental construction has been proved to be appropriate for large-scale, repetitive bridges such as long waterway crossings or urban freeway viaducts or where the aesthetics of the project are particularly important.

Current developments suggest that segmental construction will be used on a larger number of projects in the future. Standard cross sections have been developed to allow for wider application of this construction method to smaller-scale projects. Surveys of existing segmental bridges have demonstrated the durability of this structure type and suggest that additional increases in design life are possible with the use of HPC. Segmental bridges with concrete strengths of 55 MPa (8,000 psi) or more have been constructed over the past 5 years. Erection with overhead equipment has extended applications to more congested urban areas. Use of prestressed composite steel and concrete in bridges reduces the dead weight of the superstructure and offers increased span lengths.

## LOAD RATING OF EXISTING BRIDGES

Existing bridges are currently evaluated by maintaining agencies using working stress, load factor, or load testing methods. Each method gives different results, for several reasons. In order to get national consistency, FHWA requests that all states report bridge ratings using the load factor method. However, the new AASHTO Load and Resistance Factor Design (LRFD) bridge design specifications are different from load factor method. A discrepancy exists, therefore, between bridge design and bridge rating.

A draft of a manual on condition evaluation of bridges, currently under development for AASHTO, has specifications for load and resistance factor rating of bridges. These specifications represent a significant change from existing ones. States will be asked to compare current load ratings with the LRFD load ratings using a sampling of bridges over the next year, and adjustments will be proposed. The revised specifications and corresponding evaluation guidelines should complete the LRFD cycle of design, construction, and evaluation for the nation's bridges.

## LIFE-CYCLE COST ANALYSIS

The goal of design and management of highway bridges is to determine and implement the best possible strategy that ensures an adequate level of reliability at the lowest possible life-cycle cost. Several recent regulatory requirements call for consideration of life-cycle cost analysis for bridge infrastructure investments. Thus far, however, the integration of life-cycle cost analysis with structural reliability analysis has been limited. There is no accepted methodology for developing criteria for life-cycle cost design and analysis of new and existing bridges. Issues such as target reliability level, whole-life performance assessment rules, and optimum inspection-repair-replacement strategies for bridges must be analyzed and resolved from a life-cycle cost perspective. To achieve this design and management goal, state departments of transportation must begin to collect the data needed to determine bridge life-cycle costs in a systematic manner. The data must include inspection, maintenance, repair, and rehabilitation expenditures and the timing of these expenditures. At present, selected state departments of transportation are considering life-cycle cost methodologies and software with the goal of developing a standard method for assessing the cost-effectiveness of concrete bridges.

## DECKS

Cast-in-place (CIP) deck slabs are the predominant method of deck construction in the United States. Their main advantage is the ability to provide a smooth riding surface by field-adjustment of the roadway profile during concrete placement. In recent years automation of concrete placement and finishing has made this system cost-effective. However, CIP slabs have disadvantages that include excessive differential shrinkage with the supporting beams and slow construction. Recent innovations in bridge decks have focused on improvement to current practice with CIP decks and development of alternative systems that are cost-competitive, fast to construct, and durable. Focus has been on developing mixes and curing methods that produce performance characteristics such as freeze-thaw resistance, high abrasion resistance, low stiffness, and low shrinkage, rather than high strength. Full-depth precast panels have the advantages of significant reduction of shrinkage effects and increased construction speed and have been used in states with high traffic volumes for deck replacement projects. NCHRP Report 407 on rapid replacement of bridge decks has provided a proposed full-depth panel system with panels pretensioned in the transverse direction and posttensioned in the longitudinal direction.

Several states use stay-in-place (SIP) precast prestressed panels combined with CIP topping for new structures as well as for deck replacement. This system is cost-competitive with CIP decks. The SIP panels act as forms for the topping concrete and also as part of the structural depth of the deck. This system can significantly reduce construction time because field forming is only needed for the exterior girder overhangs. The SIP panel system suffers from reflective cracking, which commonly appears over the panel-to-panel joints. A modified SIP precast panel system has recently been developed in NCHRP Project 12-41.

## SUBSTRUCTURES

Continuity has increasingly been used for precast concrete bridges. For bridges with total lengths less than 300 m (1,000 ft), integral bridge abutments and integral diaphragms at piers allow for simplicity in construction and eliminate the need for maintenance-prone expansion joints. Although the majority of bridge substructure components continue to be constructed from reinforced concrete, prestressing has been increasingly used. Prestressed bents allow for longer spans, improving durability and aesthetics and reducing conflicts with streets and utilities in urban areas. Prestressed concrete bents are also being used for structural steel bridges to reduce the overall structure depth and increase vertical clearance under bridges. Precast construction has been increasingly used for concrete bridge substructure components. Segmental hollow box piers and precast pier caps allow for rapid construction and reduced dead loads on the foundations. Precasting also enables the use of more complex forms and textures in substructure components, improving the aesthetics of bridges in urban and rural areas.

## RETAINING WALLS

The design of earth retaining structures has changed dramatically during the last century. Retaining wall design has evolved from short stone gravity sections to concrete structures integrating new materials such as geosynthetic soil reinforcements and high-strength tie-back soil anchors.

The design of retaining structures has evolved into three distinct areas. The first is the traditional gravity design using the mass of the soil and the wall to resist sliding and overturning forces. The second is referred to as mechanically stabilized earth design. This method uses the backfill soil exclusively as the mass to resist the soil forces by engaging the soil using steel or polymeric soil reinforcements. A third design method is the tie-back soil or rock anchor design, which uses discrete high-strength rods or cables that are drilled deep into the soil behind the wall to provide a dead anchorage to resist the soil forces.

A major advancement in the evolution of earth retaining structures has been the proliferation of innovative proprietary retaining walls. Many companies have developed modular wall designs that are highly adaptable to many design scenarios. The innovative designs combined with the modular standard sections and panels have led to a significant decrease in the cost for retaining walls. Much research has been done to verify the structural integrity of these systems, and many states have embraced these technologies.

As the Interstate highway system of the last century is rebuilt or expanded, a premium will be placed on building larger highways within narrower corridors that are hemmed in by development and environmentally sensitive lands. This will lead to an increased use of earth retaining structures. The design of retaining structures will continue to evolve. New materials and technologies will undoubtedly surface. The challenge will be to meet this need with research into new technologies and materials to ensure safety, durability, and cost-effective earth retaining structures.

## RESEARCH

The primary objectives for concrete bridge research in the 21st century are to develop and test new materials that will enable lighter, longer, more economical, and more durable concrete bridge structures and to transfer this technology into the hands of the bridge designers for application. The HPCs developed toward the end of the 20th century would be enhanced by development of more durable reinforcement. In addition, higher-strength prestressing reinforcement could more effectively utilize the achievable higher concrete strengths. Lower-relaxation steel could benefit anchor zones. Also, posttensioning tendons and cable-stays could be better designed for eventual repair and replacement. As our natural resources diminish, the investigation of the use of recycled materials is as important as the research on new materials.

The development of more efficient structural sections to better utilize the performance characteristics of new materials is important. In addition, more research is required in the areas of deck replacement panels, continuity regions of spliced girder sections, and safe, durable, cost-effective retaining wall structures.

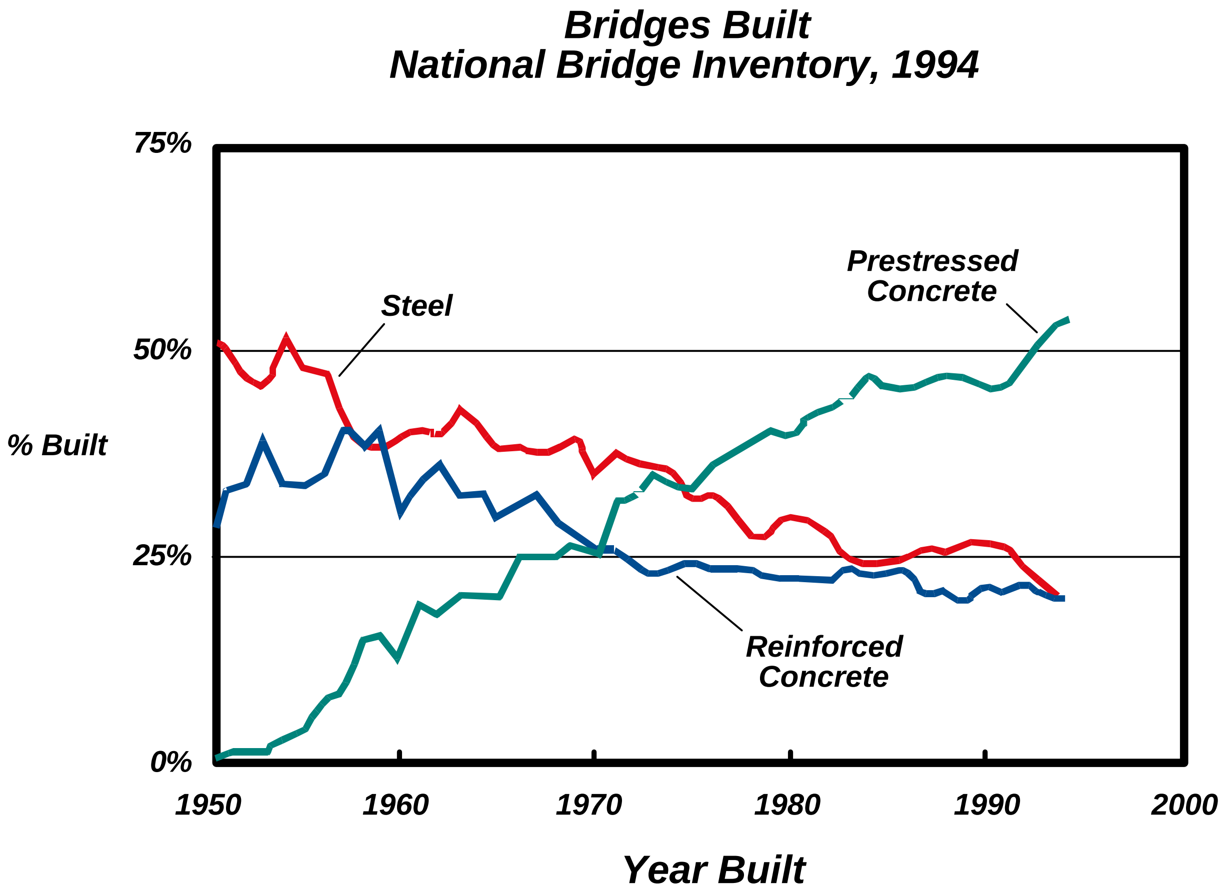
Research in the areas of design and evaluation will continue into the next millennium. The use of HPC will be facilitated by the removal of the implied strength limitation of 70 MPa (10.0 ksi) and other barriers in the LRFD bridge design specifications. As our nation’s infrastructure continues to age and as the vehicle loads continue to increase, it is important to better evaluate the capacity of existing structures and to develop effective retrofitting techniques. Improved quantification of bridge system reliability is expected through the calibration of system factors to assess the member capacities as a function of the level of redundancy. Data regarding inspection, maintenance, repair, and rehabilitation expenditures and their timing must be systematically collected and evaluated to develop better methods of assessing cost-effectiveness of concrete bridges. Performance-based seismic design methods will require a higher level of computing and better analysis tools.

In both new and existing structures, it is important to be able to monitor the “health” of these structures through the development of instrumentation (e.g., fiber optics) to determine the state of stresses and corrosion in the members.

## CONCLUSION

Introduced into the United States in 1949, prestressed concrete bridges today represent over 50 percent of all bridges built. This increase has resulted from advancements in design and analysis procedures and the development of new bridge systems and improved materials.

The year 2000 sets the stage for even greater advancements. An exciting future lies ahead for concrete bridges!



*Note: Other materials not plotted*

**FIGURE 1 Percentage of bridges built annually with three major construction materials.**