Segmental Concrete Bridges

A Major 21st Century Alternative

By Clifford L. Freyermuth

Segmental concrete bridge construction began with the use of cast-in-place cantilever technology for the Lahn Bridge at Balduinstein in Germany in 1950-1951. Glued match — cast joints for precast segmental construction were first used for the Choisy Le Roy Bridge in France in 1962.

In the U.S., precast segmental construction was first used for the John F. Kennedy Memorial Causeway in Corpus Christi, Texas in 1972. In 1974, the Pine Valley Bridge cast-in-place balanced cantilever bridge was constructed in California.

From these beginnings, both precast and cast-in-place segmental concrete bridge construction have grown to become a major component of the bridge construction industry in nearly all parts of the world. Two current projects which reflect this growth in the U.S. are the San Francisco-Oakland East Bay Skyway Bridge (Skyway Bridge) (*Figures 1 and 2*), and the Hoover Dam Bypass Bridge (*Figure 3*). At $1.047 billion, the contract for the Skyway Bridge was the first Caltrans project that cost in excess of 1 billion dollars. The contract includes the construction of twin 85.3 feet wide precast segmental bridges across Oakland Bay for a total length of 13,776 feet. Typical span lengths are 525 feet, and segment weight ranges from 500 to 800 tons. The use of these very heavy segments was possible due to water transportation from the casting yard in Stockton, California.

Bids were received on the Hoover Dam Bypass Bridge on September 16th, 2004 with a low bid of $114,000,000.00. At 1,090 feet, the segmental concrete arch span will be the fourth largest concrete arch in the world when completed. The precast segmental columns range up to nearly 300 feet in height, and the bridge deck is 880 feet above the Colorado River. The Hoover Dam Bypass Bridge is scheduled for completion in June 2008.

Figure 1: San Francisco-Oakland East Bay Skyway Bridge Construction. Photo courtesy of Kiewit/Flatiron/Manson, A Joint Venture.

These bridges clearly reflect the use of segmental concrete bridge technology for structures that would have been built with structural steel in the U.S. 30 years ago. Seven factors have contributed to growth in the use of segmental technology for major bridge projects in the U.S. and around the world:

1. Competitive initial cost.
2. Low maintenance costs.
3. Speed of construction.
4. Safety under extreme events.
5. Industrialization of the construction process.
6. Innovations in construction equipment.
7. Aesthetic appeal.

Figure 2: Segment Erection, San Francisco-Oakland East Bay Skyway Bridge Construction. Photo courtesy of Kiewit/Flatiron/Manson, A Joint Venture.

Competitive Initial Cost

The record of the past thirty years clearly indicates that segmental concrete bridges have often been selected as a result of competitive bids against alternatives using other materials and methods. This is not to imply that segmental concrete bridges are always the most economical alternative. However, the success rate of segmental bridges in competitive bids has been sufficient to establish the basic economy of segmental construction. In this context, many segmental bridges were selected through alternative bids for the Boston Central Artery Project, although major bridges in the northeast U.S. have traditionally utilized steel as a construction material. One example is the I-93 Viaducts and Ramps shown in *Figure 4*. This project includes 520,000 square feet of bridge deck. The erection methods had to accommodate spans ranging from 95 feet to 205 feet, and horizontal curve radii as short as 212 feet. Roadway widths varied from 22 feet to 96 feet. For this project, the segmental low bid was $79.3 million, saving the Massachusetts Turnpike Authority in excess of $27 million over the lowest steel alternate bid.

Segmental concrete bridges have also competed successfully on smaller projects against alternates with prestressed concrete beams or bulb tees. In 1997, the approximately $20 million bid for the segmental alternate for the Sailboat Bridge in Oklahoma was $1.1 million lower than the lowest bid for a bulb tee superstructure. The Sailboat Bridge featured twin precast concrete segmental bridges with spans of about 122 feet and a total length of 3,044 feet. The roadway width of each bridge is 41 feet 3 inches. The bridges feature an as-cast riding surface with epoxy joints between segments.

Low Maintenance Costs

Possibly one of the best measures of durability and related maintenance cost is the National Bridge Inventory data, which is based on bridge inspection reports by personnel from State Departments of Transportation compiled by the Federal Highway Administration (FHWA). A 1997 article by FHWA engineers indicated that about 110,000 of the 470,000 bridges on the Federal Highway System were structurally deficient. While steel bridges represent about 40 percent of the overall bridge total, they include about 60 percent of the structurally deficient bridges. The number of bridges with structural deficiencies associated with various materials and various bridge elements is shown in *Figure 5*. (The S/A term

Figure 3: Hoover Dam Bypass Bridge. Drawing courtesy of T.Y. Lin International.

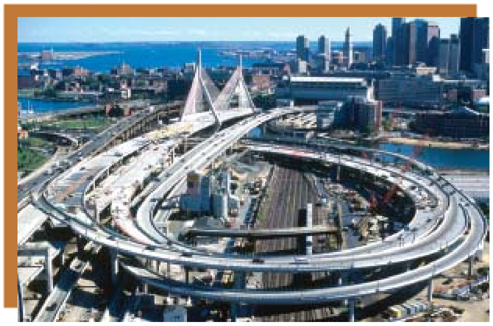

Figure 4: Boston Central Artery/Tunnel, I-93 Viaducts and Ramps. Photo courtesy of Figg Engineering Group.

in *Figure 5* refers to structural adequacy.) Deficient bridges in the S/A category have a very low load rating. Only 3 percent of the 110,000 structurally deficient bridges (about 3,300 bridges) utilized prestressed concrete, and there are no known structurally deficient segmental bridges. Although most segmental bridges are less than 30 years old, the National Bridge Inventory data indicates that bridges built by other materials and methods do exhibit structural deficiency at earlier ages.

Due to longitudinal and transverse prestressing, segmental concrete bridge decks are virtually crack-free, which provides greatly enhanced durability in aggressive environments. Additional corrosion protection in areas where deicer chemicals are used can be economically provided by an additional inch or inch and a half of concrete cover over top slab reinforcement placed at the time the segments are cast. The use of integral overlays also eliminates the delamination problems that have sometimes occurred with bonded concrete overlays.

Speed of Construction

Construction speed varies for different types of segmental bridges, but in most cases all types of segmental construction offer relatively rapid construction speed with respect to possible alternatives for the same site constraints.

The Victory Bridge over the Raritan River in New Jersey provides a current example of speed of construction for precast segmental bridges (*Figure 6*). The Victory Bridge incorporates twin southbound and northbound bridges, each 3,971 feet in total length. The southbound bridge was opened to traffic just 15 months after the Contractor received notice to proceed. After demolition of the existing bridge with a swing span that opened an average of 1,100 times a year, the northbound bridge was erected in just nine months. The new bridge features a United States record for the 440 foot fully match cast precast concrete segmental main span. The bridge also incorporates precast piers as tall as 100 feet that were erected in a single day, and the use of an integral concrete wearing surface cast with the segments. Main span pier segments are 21 feet deep and weigh 128 tons. By casting them in halves, the same erection equipment could be used for both pier and typical segments. Erection of two 3971 foot long bridges over water with pier heights ranging to 100 feet, and a main span of 440 feet, in a total of 24 months reflects the construction speed possibilities of precast segmental bridges.

Safety under Extreme Events

Research at the University of California, San Diego, undertaken in reference to design of the San Francisco-Oakland East Bay Bridge (*Figure 10*) has confirmed that the strength and ductility of segmental superstructures, and monolithic superstructure-pier connections, greatly exceeds the demand of the design earthquake. This result applies regardless of whether external (within the cell of the box girder) or internal (within the concrete cross section) post-tensioning tendons, or a mixture of external and internal tendons, is used. However, this research does indicate that use of all external tendons provides somewhat more ductility than results with use of internal tendons. Further, since external tendons remain elastic (stressed below the yield point) in an earthquake, there would be very little residual deflection following a seismic event, and the damage to the superstructure would be significantly less than would result when internal tendons were used. In the superstructure-pier seismic test depicted in *Figure 7*, cracking was confined to the pier, and the superstructure remained uncracked. This result reflects the strong beam, weak column seismic design philosophy.

Figure 6: Victory Bridge, New Jersey. Photo courtesy of Figg Engineering Group.

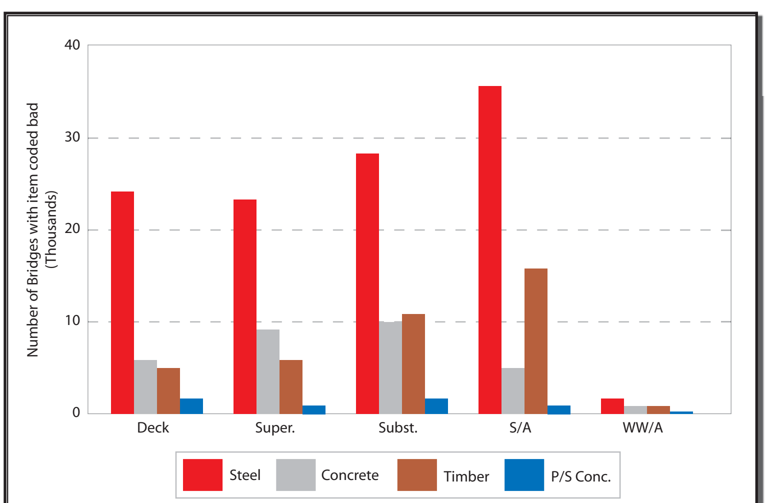

Figure 5: FHWA Data on Structurally Deficient Bridges on the Federal Highway System - 1997

Figure 7: Segmental Superstructure-Pier Seismic Test at the University of California, San Diego, 2004

Figure 8: Mobile Segment Erection Device, Dallas High Five Interchange, 2002-2004. Photo courtesy of Parsons.

The exceptionally severe 2004 hurricane season demonstrated the ability of segmental concrete bridges to withstand extreme wind loads. Hurricane Ivan came ashore on the Gulf coast near Mobile, Alabama and Pensacola, Florida with winds up to 130 miles per hour and storm surges as high as 30 feet. Five major segmental and concrete cable-stayed bridges stood strong with no structural damage despite a direct hit from Hurricane Ivan. Other segmental and cable-stayed Florida bridges also withstood winds associated with hurricanes or tropical storms without structural damage. Winds and storm surges associated with Hurricane Ivan did inflict significant damage on bridges utilizing other types of construction. The Interstate 10 bridge in Pensacola is now being replaced.

Figure 9: Articulated Erection Gantry for use on Curved Alignment. Skytrain Millenium Line, Vancouver, British Columbia.

[At the time of producing this article for publication, the available information indicates that four major segmental and cable-stayed bridges performed very well and were, for practical purposes, undamaged by Hurricane Katrina.]

Industrialization of the Construction Process

The inherent economy of segmental concrete bridges is, to a significant degree, the result of the industrialization of the construction process. One precast segment is normally produced each day from short-line casting forms. While there are minor variations in segments, the procedure remains basically the same from day to day. After a short learning

Figure 10: San Francisco-Oakland East Bay Skyway Bridge Segment Erection Device. Photo courtesy of Kiewit/Flatiron/Manson, A Joint Venture.

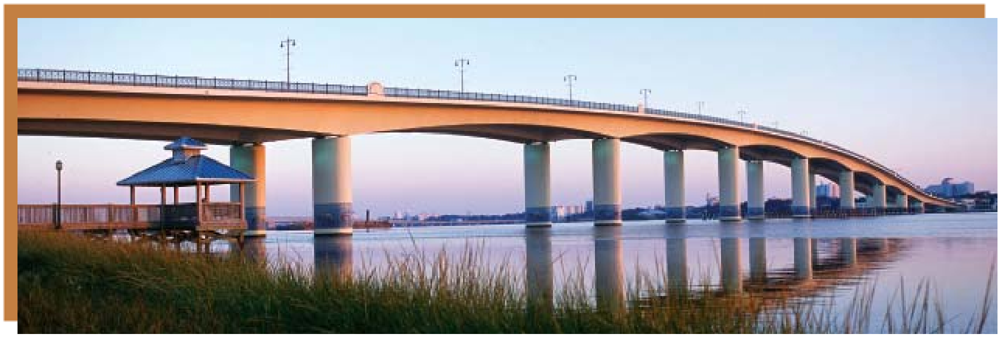

Figure 11: Broadway Bridge in Daytona Beach, Florida. Photo courtesy of Figg Engineering Group.

curve, construction crews become highly efficient in producing segments. The major construction effort is transferred from the bridge site to the "factory" environment of the casting yard. For cast-in-place segmental bridges, the construction process is similar but it takes place at the bridge site.

While the time required for construction of a typical segment (usually about 5 days) is much longer than precast segmental construction, this should be considered in the context of the longer span lengths for which cast-in-place balanced cantilever construction is used (usually for spans of 350 feet or more). At the beginning of superstructure construction, there is a learning curve for the construction crew which results in a much slower pace of construction.

Innovations in Construction Equipment

Growth in the construction of segmental bridges has led to innovations and refinement of construction equipment. A mobile rubber-tired segment erection device developed for construction of the Dallas High Five Interchange in 2002-2004 is shown in *Figure 8*. An articulated overhead gantry for use on curved alignment is shown in *Figure 9*. Self launching erection devices were developed for lifting the 750 ton segments of the San Francisco-Oakland East Bay Skyway Bridge (*Figure 10*).

Growth in the use of segmental bridges in the U.S., and worldwide, has accelerated development of specialized equipment for forming, transporting and erecting segments. The availability of this specialized equipment increases the speed of construction and provides additional economies in construction. However, more sophisticated equipment is expensive and may only be feasible for large projects. An inventory of used equipment is available from suppliers which may be more appropriate for more moderate sized projects.

Aesthetic Appeal

Segmental concrete bridges have been widely recognized, and have received many awards, for their inherent aesthetic appeal. The Broadway Bridge in Daytona Beach, Florida shown in *Figures 11* & *12* is an example of the aesthetic potential of segmental concrete bridges.

Conclusion

Over the past thirty years, segmental concrete bridges have become a primary alternative for the construction of major bridges in the U.S. The applicable span range for various types of segmental bridges extends from 100 feet to at least 1,500 feet for segmental cable-stayed bridges. The factors discussed above that have led to the dramatic growth experienced in use of segmental bridges are considered to provide the basis for continued growth in construction of segmental concrete bridges in the 21st century.▪

Figure 12: Broadway Bridge in Daytona Beach, Florida. Photo courtesy of Figg Engineering Group.

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