Design Challenges and Construction Benefits of Precast Segmental Rail Bridges

by

Amy R. Kohls, P.E., S.E.
Director
Texas Office
Figg Bridge Engineers, Inc.
10000 North Central Expressway
Suite 1300
Dallas, Texas 75231
Telephone: 214-363-3444
Facsimile: 214-363-4435

and

D. Brice Urquhart, P.E.
Project Manager
Lee Roy Selmon Crosstown Expressway Field Site
Figg Bridge Inspection, Inc.
1103 North 22nd Street
Suite F
Tampa, Florida 33605
Telephone: 813-241-6148
Facsimile: 813-241-6147

Word Count: 3,242 words

+ 17 pictures (4,250 words)

TOTAL = 7,492 words
ABSTRACT

Precast segmental concrete design and construction have successfully been used for all types of rail bridges in various environments. For example, the John T. Collinson Bridge in Pensacola, Florida is a main artery for the CSX Railroad over water and was the first precast concrete segmental bridge used for heavy rail in the United States. WMATA and MARTA are mass transit agencies in Washington D.C. and Atlanta, respectively, that have successfully utilized this type of construction for their rail bridges in their urban conditions. Most recently, the JFK Light Rail System within the JFK Airport will move an estimated 30 million passengers a year through one of the most congested airports in the world. Precast segmental bridge options provided the designer with the ability to meet or exceed the needs of the owner.

Rail bridges, by their nature, have significant design and construction challenges. Precast segmental construction provides solutions to these challenges and exceeds project requirements. Benefits are provided through the speed of production both in casting of the segments and erection and the ability to construct in a congested environment. With production typically occurring off-site in a controlled environment, the quality of the precast bridge can be assured with regard to color consistency, meeting or exceeding strength requirements and achieving a bridge that requires little or no maintenance. This construction method also is an advantage in protecting sensitive environments from disruption during construction.
INTRODUCTION

Rail bridges are unique when compared to standard highway bridges because of the challenges associated with this type of structure. A specialized approach must be taken when considering these structures in terms of design, construction, and long-term maintenance.

There are different types of rail systems: heavy rail, mass transit, and light rail systems. Each has specific requirements associated with the type of system; however, the same basic challenges exist on each and can be successfully accomplished using precast segmental construction.

Precast segmental construction has been used for heavy rail, mass transit, and light rail systems throughout the country. Owners of these projects selected this construction alternative since they determined it to be the optimal solution for their structure needs. Significant and quantifiable benefits were realized for these owners in their major rail projects.

DESIGN CHALLENGES FOR RAIL STRUCTURES

There are several factors to be considered in the design of rail structures. The differences between typical highway bridges and rail bridges are not simply an increase in the live load due to the heavier train loadings. These differences can be discussed in terms of loadings, service considerations, and long-term maintenance of the structures.

Loadings

In the design of a rail bridge, the following considerations should be made:

- Increased live load – the typical train loading is significantly larger than the truck loads used in typical highway design.
- Derailment load – the design must consider the effects of a train derailing, including the impact from such an occurrence.
• Rail/structure interaction forces – the rails are typically continuously connected to the bridge deck, resulting in differential expansion and contraction effects between the different materials.

• Longitudinal braking forces from trains – the braking force from the train is typically larger loading than the longitudinal force used in the design of highway bridges.

• Lateral rolling forces from trains – the effect of the train’s lateral movement is carried through the rails into the bridge deck.

• Different critical section locations – the critical sections in a rail bridge under train loading will be different than those typically anticipated under highway loading.

Precast segmental construction successfully solves these design issues through the nature of the structure type. The concrete box girder is torsionally rigid due to its closed trapezoidal shape, making the section effective in resisting large torsion loads from the train derailment loads and other lateral forces. Additionally, the concrete section can be easily designed to accommodate the loads that are experienced by a rail bridge.

**Service Considerations**

The design criteria for a rail bridge include different serviceability criteria than those for highway bridges, including:

• Vibration and deflection criteria – the limitations established for vibrations and deflections for rail structures are more stringent than typical highway loading due to the sensitivity of the train operations to structure movement.

• Fatigue considerations – the bridge will be exposed to more significant cyclic movements under train loadings, requiring greater consideration to structure design and details.
• Uplift forces at piers – the location of the train on the bridge will result in more frequent occurrences of uplift forces at piers that must be addressed in the superstructure to substructure connection.

• Noise control – the noise level created by trains is often a concern in areas where the alignment passes residential, commercial, or parklands.

Concrete is a natural dampener for both noise and vibration. This is beneficial for rail structures where both noise and vibration criteria are stringent. The concrete segmental box girder further enhances the dampening due to the rigidity of the closed box shape. This helps to reduce vibration and deflection in the structure, improving the serviceability of the bridge under train loadings.

**Long Term Maintenance**

It is always important in the design of any structure to consider future maintenance and to design a structure that will satisfy its functional requirements throughout its anticipated design life. For rail structures, this may be considered to be even more imperative due to the following:

• Difficulty of maintaining train traffic during maintenance – it is often difficult to keep an active rail line open during significant maintenance because it is not possible to direct the train along any other path than that set by the rails. With a traffic bridge, as a comparison, it is possible to close lanes or route traffic onto a shoulder during times of maintenance.

• Increased difficulty in replacement – a longer structure life must be considered in the design to take into account the difficulty to replace a rail structure. To build a replacement bridge, it is often not possible to reroute the rail to a parallel structure, so the new bridge must be built in the existing footprint, causing disruption to the active rail line.
Precast segmental bridges are highly durable structures for a number of reasons. The precasting of the structural elements allows the casting to occur in a controlled, factory-like environment instead of on-site in differing conditions. This results in a higher quality product. The superstructure is post-tensioned in both the transverse and longitudinal directions, placing the bridge deck in compression at all times. This eliminates the possibility of cracking of the bridge deck and intrusion of corrosive agents that would damage the mild steel reinforcement and the post-tensioning in the deck. Additionally, concrete itself is a highly durable material that does not need to be coated or treated to prevent corrosion. These factors combined with low-maintenance detailing of the bearings and expansion joints enable the structure to easily achieve its design life with minimal maintenance by the owner.

CONSTRUCTION CHALLENGES OF BUILDING WITHIN GIVEN ENVIRONMENT

Construction over Traffic

Mass transit is a major part of many urban environments. With this, the challenge of building within existing vehicular traffic is always involved. With the continued acceleration of suburban development, the major traffic corridors in most metropolitan areas are exceeding their capacity with commuters. Cities are now in need of mass transit facilities that can be constructed with minimal disruption to existing traffic.

Precast segmental construction has been proven in numerous applications to satisfy the requirement of maintaining traffic during construction. This was accomplished on the San Antonio “Y” Project in Texas where 4.4 miles of precast concrete segmental bridges were built over vehicular and Norfolk Southern Railroad traffic and within existing right-of-way without disrupting traffic. (See Figure 1.) Underslung triangular trusses and a bridge mounted crane
were used to construct the bridge from above, while allowing trains and vehicular traffic to continue beneath and directly adjacent to construction. (See Figures 2 and 3.) This project was completed in 1989 as the first precast concrete segmental elevated interstate in Texas, totaling 1.3 million square feet and saving the owner 11.6% ($8.5 million in savings) from the alternate design. (See Figure 4.) This same construction technology can be applied to any type of structure – such as rail bridges – in urban environments.

**Construction in Environmentally Sensitive Sites**

Construction occurring over environmentally sensitive waters or wetlands requires specific attention to erection methods. Similarly to erecting over active traffic, building from the top of the completed bridge deck allows construction to continue without disrupting sensitive areas. In this type of environment, precast segmental construction is particularly suited because the majority of the concrete operations occur off-site. The precast segments can be delivered across the completed bridge deck and erected into place.

This procedure was accomplished on the James Burrows Edwards Bridge over the Wando River, which was completed for the South Carolina Department of Transportation in 1989. (See Figure 5.) These 7,900’ long twin highway bridges were designed with typical 150’ spans with environmental protection of the wetlands as a prime concern. (See Figure 6.) Both the superstructure segments and the pier segments were constructed from precast post-tensioned elements. This special care in the design phase allowed the contractor to be able to preserve the wetlands beneath the bridge during construction.

**Building over Water**

When building over water, efficiency is achieved through the simplification of operation. Precast segmental construction allows off-site casting that removes complicated casting procedures and
unpredictable weather from the critical path. Once the segments are cast, they can easily be barged to the erection site, lifted onto the erection truss using a barge-mounted crane, and assembled. This procedure was accomplished successfully on the John T. Collinson Bridge in Florida for CSX Transportation. (See Figure 7.) This project is discussed in greater detail in the next section as the first case study.

**CASE STUDIES – PRECAST CONCRETE SEGMENTAL RAIL STRUCTURES**

The previous discussions have included how precast segmental construction can be used to solve bridge construction challenges for several environmental and congested conditions. The following projects are completed bridges where precast segmental construction was used for heavy rail, mass transit, or light rail systems. These projects demonstrate the success of this construction method and can be resources for other situations with similar challenges.

**John T. Collinson CSX Rail Bridge, Pensacola, Florida**

This bridge was completed for CSX Transportation in 1988 as the first precast segmental bridge for heavy rail use in the United States. (See Figure 7.) The bridge was designed for Cooper E90 train loading, hurricane winds, and barge impact. At 11,370 feet, it is the longest rail bridge in the United States. It crosses the Escambia Bay with typical 100’ simple spans and a 170’ main span over the navigation channel. An interesting feature about this bridge is its contingency plan for a derailment condition. In the event of a derailment that results in the loss of a span, there is an entire span of segments and the erection truss in storage near the site, ready to be installed to open the bridge to operation immediately. This demonstrates the flexibility of precast segmental construction and the ability to tailor the construction method to the specific needs of an owner.
**Metropolitan Atlanta Rapid Transit Authority (MARTA) CS360 & CN480, Atlanta, Georgia**

Completed in 1983, MARTA CS360 and CN480 were the first precast segmental concrete bridges built for rail use in the United States. (See Figure 8.) The precast segmental design was also the first use of twin triangular trusses located on each side of the box girder and supporting the box from underneath the wings. (See Figure 9.) This span-by-span construction method allowed adequate vertical clearance while building over traffic and in heavily congested areas. (See Figure 10.) MARTA CS360 is 5,230’ long, carrying two trackways and consisting of simple spans ranging in length from 70’ to 100’. MARTA CN480 is 1,900’ long with span lengths ranging from 75’ to 143’. A single box section – 7’ deep and 30’-4” wide – was used for the entire combined alignment of 7,130’.

**Washington Metro Area Transit (WMATA) E6F Greenbelt Parkway, Washington, D.C.**

These twin precast segmental transit rail viaducts were completed in December 1990. The bridges consist of a combined 3,846’ structure length with typical spans of 109’ and with variations from 49’ to 133’. (See Figure 11.) Span-by-span construction was used with a steel erection truss supporting the box girders under the bottom soffit, easily accommodating the horizontal curvature radii of 1,200' of the viaduct without disturbing the nearby wetlands. To accommodate track super-elevation that varies from 10% to 0% while minimizing the vertical profile, two parallel box girders were chosen for the superstructure. (See Figure 12.) Each girder is 15.5’ wide and 7’ deep and carries a single track with rails fixed directly to the superstructure.

The successful low bid contractor selected the precast segmental design over a concrete cast-in-place on falsework design, providing a savings to WMATA that is reflected in the low bid of $9.4 million for their key project.
Washington Metro Area Transit (WMATA) F10 Suitland Parkway, Suitland, Maryland

This mass transit project is an extension of the existing transit system in Washington, D.C. Project challenges included building over busy Suitland Parkway, minimizing disruption to environmentally sensitive wetlands, and providing an aesthetic solution for the adjacent national parklands. (See Figure 13.) Precast concrete segmental construction successfully fulfilled all of the project’s needs. The total project length of 2,620’ consisted of spans ranging from 56’ to 151’ with typical spans of 132’. The simple spans were built using span-by-span construction built from above to protect the wetlands and maintain traffic on the parkway below. The constant 8’-8” deep and 32’-5” wide box was used throughout the project, which included ten horizontal curves, two vertical curves, and cross-slopes of up to 12%. The $10.7 million bridges were completed in February 1999, well ahead of the October 1999 anticipated project completion. (See Figure 14.)

JFK Light Rail System, New York City, New York

Nearly nine miles of elevated structure were built in the congested JFK Airport and surrounding areas in New York City. (See Figure 15.) This light rail system was built to connect the separate terminals of the airport to each other, long-term parking, the commuter rail line, and the New York subway system. The project utilized 5,409 precast segments – the most of any bridge in the United States. Construction was completed over existing at-grade roadways with traffic flowing. One 2.3-mile section of the project was built in the median of the existing Van Wyck Expressway. (See Figure 16.) Three lanes of traffic in each direction continued as construction was progressed at a rate of 2½ spans of 120’ per week. The finished base of the column and barriers is only 7’-8” in order to utilize the median as the only available space for support columns.
Precast segmental construction was particularly innovative for this aggressive project. In order to simplify the complexities on the project, two 7’-0” deep box sections were utilized – one for the single track section (19’-3” wide) and one for the dual track section (31’ wide). These two sections were able to accommodate variable span lengths from 62’ to 156’ and horizontal curvature with radii as small as 212’.

Precast segments were cast in Cape Charles, Virginia, barged 250 miles to Camden, New Jersey, and then trucked over 100 miles to the site. Storage of materials on-site was a significant issue, so planning of segment delivery was critical. The average storage time at the site was two days before erection. The planning and coordination was successful, indicated by the completion of nine miles of elevated structure in only 26 months, almost 3 months ahead of schedule.

The closed box girder shape creates a smooth underside for the structure, allowing clean lines and uncluttered appearance. The concrete mix was closely regulated, using specific materials to generate the same concrete color whether it was precast (superstructure), cast in place (substructure), or mixed on-site (closure pours). This attention to detail resulted in an aesthetically pleasing structure for the airport and surrounding area. (See Figure 17.)

CONCLUSION

Precast segmental construction brings significant and quantifiable benefits to owners. Case studies of completed projects demonstrate how design and construction challenges were solved through the use of this construction method. These challenges are similar to many rail structures and these solutions can be tailored to each specific project.

In summary, these significant and quantifiable benefits include:

- Maintain existing traffic throughout construction
Minimize amount of new right-of-way acquisition by building within owners’ existing ROW – saves money for the owner

Minimize impacts on the environment by building within an existing corridor – no need to create a new alignment with a new set of environmental impacts

Accelerate project completion by minimizing time required for ROW acquisition and new environmental studies

Reduce impacts to environmentally sensitive waters and wetlands by building from above

Increased quality by precasting structural elements off site in factory-like conditions

Reduce construction time by having concurrent substructure and superstructure casting

Improve aesthetics with slender columns and closed box girder shape

The future of construction for rail bridges will include even more heavily congested urban sites, similar environmentally sensitive areas, and the same need for low-maintenance and long-lasting bridges. With these benefits and proven resources of completed bridges, precast segmental construction will be the optimal solution for many rail projects in both urban and rural environments.

ACKNOWLEDGEMENTS

The authors and the entire team at Figg Engineering Group would like to thank the owners of the bridges mentioned in this paper:

- CSX Transportation
- Metropolitan Atlanta Rapid Transit Authority
- Port Authority of New York and New Jersey
- South Carolina Department of Transportation
• Texas Department of Transportation
• Washington Metropolitan Area Transit Authority

We wish to express our sincere gratitude for the opportunity to be involved in your exciting bridge projects.
LIST OF FIGURES

Figure 1  San Antonio “Y” Bridges – Aerial view of construction in downtown San Antonio.

Figure 2  San Antonio “Y” Bridges – Construction from the top of the completed bridge adjacent to existing traffic.

Figure 3  San Antonio “Y” Bridges – Construction of bridges over active rail traffic.

Figure 4  San Antonio “Y” Bridges – Completed project was the first precast segmental elevated interstate in Texas.

Figure 5  James Burrows Edwards Bridge over the Wando River – Completed in 1989 utilizing precast segmental construction.

Figure 6  James Burrows Edwards Bridge over the Wando River – Typical 150’ spans built from the top to protect the wetlands.

Figure 7  John T. Collinson Bridge – First precast concrete segmental bridge for heavy rail use in United States.

Figure 8  MARTA CS360 and CN480 – First precast concrete segmental bridges built for rail use in the United States.

Figure 9  MARTA CS360 and CN480 – First use of twin triangular trusses for span-by-span construction.

Figure 10  MARTA CS360 and CN480 – Construction continued through congested Atlanta, minimizing disruption to existing traffic.

Figure 11  WMATA Greenbelt Parkway – Completed project.

Figure 12  WMATA Greenbelt Parkway – Twin box girders accommodated super-elevations up to 10%.
Figure 13  WMATA Suitland Parkway – Precast segmental construction was built over busy Suitland Parkway.

Figure 14  WMATA Suitland Parkway – Completed project.

Figure 15  JFK Light Rail System – Aerial view of JFK Central Terminal Area with completed structures.

Figure 16  JFK Light Rail System – Construction of elevated track in median of Van Wyck Expressway. Column and barrier width is 7’-8”.

Figure 17  JFK Light Rail System – Completed elevated track incorporated details to create an aesthetically pleasing structure.
Figure 1

San Antonio "Y" Bridges – Aerial view of construction in downtown San Antonio.
Figure 2

San Antonio "Y" Bridges – Construction from the top of the completed bridge adjacent to existing traffic.
Figure 3

San Antonio "Y" Bridges – Construction of bridges over active rail traffic.
Figure 4

San Antonio “Y” Bridges – Completed project was the first precast segmental elevated interstate in Texas.
Figure 5

Figure 6

James Burrows Edwards Bridge over Wando River – Typical 150’ spans built from the top to protect the wetlands.
Figure 7

John T. Collinson Bridge – First precast concrete segmental bridge for heavy rail use in United States.
Figure 8

MARTA CS360 and CN480 – First precast concrete segmental bridges built for rail use in the United States.
Figure 9

MARTA CS360 and CN480 – First use of twin triangular trusses for span-by-span construction.
Figure 10

MARTA CS360 and CN480 – Construction continued through congested Atlanta, minimizing disruption to existing traffic.
Figure 11

WMATA Greenbelt Parkway – Completed project.
Figure 12

WMATA Greenbelt Parkway – Twin box girders accommodated super-elevations up to 10%.
Figure 13

WMATA Suitland Parkway – Precast segmental construction was built over busy Suitland Parkway.
Figure 14

WMATA Suitland Parkway – Completed project.
Figure 15

JFK Light Rail System – Aerial view of JFK Central Terminal Area with completed structures.
Figure 16
JFK Light Rail System – Construction of elevated track in median of Van Wyck Expressway.

Column and barrier width is 7’-8”.
JFK Light Rail System – Completed elevated track incorporated details to create an aesthetically pleasing structure.