US 90 BRIDGE OVER BILOXI BAY

Patrick Cassity, PE, SE, Parsons, Chicago, IL
Tom Tavernaro, PE, GC Constructors, Biloxi, MS

ABSTRACT

This $338.6 million design-build project includes replacement of a 1.6 mile long bridge over Biloxi Bay that was destroyed by Hurricane Katrina. The new bridge consists of a 250 feet navigation span comprised of spliced bulb-tee girders that vary in depth from 12 ft. at the piers to 6.5 feet at mid-span. The approach spans consist of prestressed bulb-tee girders with span lengths of 85 to 150 feet. The piers are subjected to vessel collision loads ranging from 200 to 2850 kips and are supported by waterline footings with precast piles. The total project length is 2.4 miles and includes roadway reconstruction and a new 800 feet long steel girder bridge over the CSX Railroad. The majority of the design was completed in just 6 months to allow the roadway to be opened to 1 lane of traffic in each direction by November 2007, only 18 months from notice to proceed. The entire project is to be completed in April 2008. The focus of this paper will be the design and construction of the bridge across the bay.

Key Words: Katrina Reconstruction, Prestressed Girder, Spliced Girder, Precast Pile, Waterline Footings, Vessel Collision, Design-Build

INTRODUCTION

Hurricane Katrina made landfall on August 29, 2006, devastating the Gulf Coast. The US 90 Bridge over Biloxi Bay connecting Biloxi, MS to Ocean Springs, MS was one of many major highway and railroad bridges knocked out of service due to extensive storm damage. The Mississippi Department of Transportation and Federal Highway Administration elected to replace the damaged bridge with a new high level bridge utilizing the design-build project delivery method.

This fast-track $338.6 million design-build contract was awarded to GC Constructors (GCC) with Parsons as the lead design firm. GCC is a joint venture of Massman Construction Co., Traylor Brothers Inc., and Kiewit Southern Co. with Massman as the managing partner. In just 18 months from notice to proceed the bridge will have one lane open to traffic in each direction in November 2007 with the entire project complete in only 22 months in April 2008. The entire project is 2.4 miles long and includes a 1.9 mile bridge over Biloxi Bay and an 800 foot long bridge over the CSX Railroad.

ORIGINAL BRIDGE

The original dual bridges consist of low level approach spans with a bascule navigation span. The approach spans are comprised of simple span prestressed, precast girders cast integrally with the deck and spanning 52 feet. The 33 foot wide superstructure units weigh 340 kips and are supported on pile bents.

Fig. 1 Storm Damaged Bridge

The eye of the storm passed 60 miles west of Biloxi, MS. Peak wind gusts of up to 100 mph, a peak storm surge height of 22 feet and waves of up to 8 feet occurred in the bay. In general, spans that had a low-chord elevation of 23 feet or less were badly damaged while higher spans remained relatively intact. A lot of the low level superstructure units were thrown off of the pile caps and into the water with some of them even flipping upside down.

A hydraulic study[1] of the Biloxi Bay Bridge concluded that because the bridges were damaged above the elevation of the still water level, the wave-induced loads due to wave crests hitting the decks were the primary damaging agent. These waves produced both a horizontal and uplift force large enough to overcome the bearing connection capacity. Buoyancy loads due to trapped air under the deck as the waves crested and the surge rose were likely only of secondary importance.

OVERVIEW OF NEW BRIDGE

The new bridge consists of dual structures each carrying three lanes of traffic. The eastbound bridge also has a 12 foot shared use path. The total out to out width is 129 feet. Aesthetics were an important consideration in the design development due to the adjacent communities' desire for an attractive structure. Therefore, the fascia girders will be colored blue-green using a concrete coating and formed concrete surfaces of the superstructures and substructures will be colored antique ivory. The pedestrian railing along the shared use path is an ornamental aluminum picket railing. There are also three overlooks spaced along the path with a bench located at each. The outside traffic barriers are an open concrete barrier rather than the traditional, solid New Jersey configuration. At night the bridge will be illuminated with a string of ornamental necklace lights attached to the fascia girders and edge accent lights on the piers.

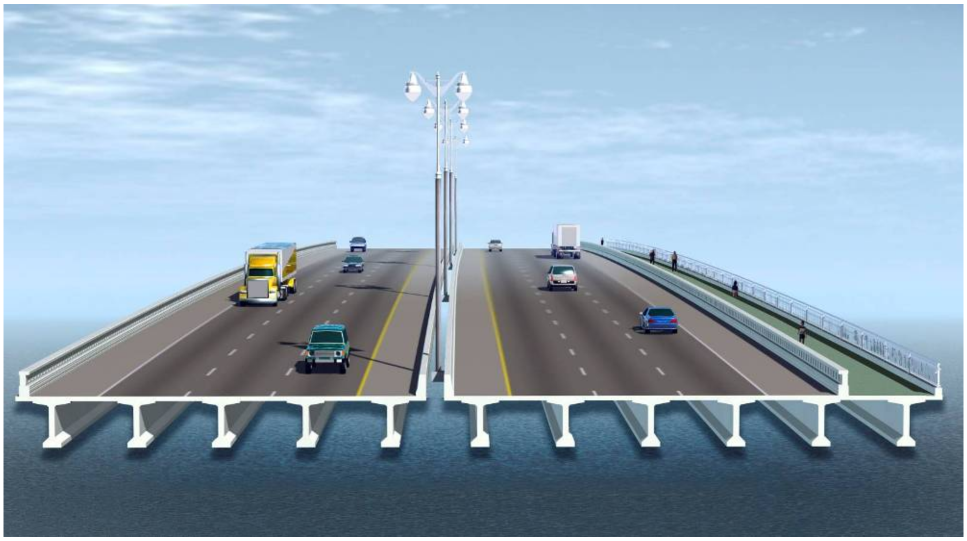

Fig. 2 Cross Sectional Rendering of New Bridge

The deck is supported by precast, prestressed bulb-tee girders at a typical spacing of approximately 12 feet. The roadway alignment is curved at each end to shift the new bridge's alignment 150 feet south of the original bridge. The curved portion of the west low level approach has 11 spans of 85.75 feet using 54 inch girders. On the tangent portion, there are 30 spans of 120 feet using 72inch girders. The curved portion of the east low level approach has 6 spans of 85.42 feet using 54 inch girders and then has 3 spans of 120 feet using 72 inch girders in the tangent section. The high level approaches on each side of the main channel unit consist of 9 spans of 150 feet using 78 inch girders. The majority of the approach spans consist of three span units. The 3-span channel unit has a 250 foot main span with 200 foot side spans and is comprised of 12 foot deep haunched segments over the piers and modified 78 inch girders for the drop-in and end segments. The 54 inch girders were transported to the site via truck and the rest of the girders were transported via barge.

Abutments 1 and 72 are supported on 18 inch precast, prestressed piling. All piers are supported by waterline footings and precast, prestressed piles with Piers 2 to 40 and 65 to 71 using 24 inch piles and Piers 41 to 64 using 30 inch piles. The piles were transported to the site via barge.

Fig. 3 Night Rendering of Main Span

The massive reconstruction efforts along the Gulf Coast after Katrina produced an overwhelming demand on the precast industry and represented a significant supply and schedule risk for this project. Therefore, the design was developed to diversify the required precast piling and girders and minimize the specialty products that only a few precastors are capable of producing. This provided GC Constructors with significant redundancy in potential suppliers during construction should a specific precastor be unable to deliver products according to the required schedule. This is the main reason that 72 inch girders were used extensively even though longer spans utilizing 78 inch girders are more economical. In addition, 36 inch piles were completely avoided due to the lack of producers of this product even though the significant vessel collision loads are more effectively resisted with larger piles.

The vertical profile of the bridge at each end slopes up rapidly until the low-chord elevation is above the critical wave height for the 100 year storm. This is the most effective and reliable method of guarding against future damage to the bridge from a hurricane. In addition, 18 inch tall concrete shear keys are used on those portions of the superstructure below the critical elevation to help keep the superstructure from being knocked off of the piers during a storm.

GEOTECHNICAL PROGRAM

There is no more important early critical path activity on design-build projects than geotechnical investigation and engineering. The input from this activity is necessary for the foundation and embankment design to be completed which are the first activities that a contractor wants to begin in the field. In addition, pile quantity growth and installation schedule risk were two of the largest risks to the design-build team on this project. Therefore, it was important that a well engineered and planned geotechnical program be developed during the bid phase and then be rapidly implemented once our team was identified as the successful bidder.

Fig. 4 Axial Static Load Test of 24 inch Pile

The subsurface conditions over most of the site consist of clays ranging from very soft at the mudline to stiff clays at a depth of 80 to 100 feet. There are some very dense sand layers beneath the soft clay layers at the far east end of the bridge. Since the vast majority of the piles are friction piles in clay, it was critical to determine the set-up curves and validate required pile lengths using an indicator pile program. The target ultimate capacity was 200, 450 and 550 tons for the 18, 24 and 30 inch piles respectively. A factor of safety of 2.0 was used since both statnamic and static load testing were performed.

A total of 19 indicator piles were driven off alignment and monitored with dynamic pile testing equipment. CAPWAP analyses were also performed. Pile restrikes were carried out at various intervals up to 28 days to determine the pile set-up curves. Enough data was gathered to reliably predict final pile capacities without performing restrikes during production pile installation. The elimination of restrikes during production piling installation allowed equipment and personnel to be focused on getting the bridge built within the accelerated schedule rather than testing piles.

A static and statnamic axial load test was performed on separate 24 inch piles and two statnamic tests were performed on 30 inch piles. The static axial test was used to validate the results of the statnamic test. The cost and time associated with statnamic testing is significantly less than static tests for large piles. In addition, a statnamic lateral load test was performed for each pile size to provide validation of the soil structure interaction modeling for vessel collision analysis.

Fig. 5 Statnamic Axial Load Test of 30 inch Pile

PIER OPTIMIZATION

One of the most challenging aspects of the design was to develop an economical approach to pier and foundation construction that addressed the wide range in geometric and loading conditions. The piers vary in height from 6 to 90 feet. The maximum total vertical reactions range from 1000 to 7000 kips with vessel collision loads ranging from 200 to 2850 kips at the main channel. The goal was to develop a design that could be built using an assembly line type approach that minimizes variability in formwork and equipment.

The solution was to use two column piers with waterline footings supporting each of the bridges. Pile bent and single column hammerhead piers were considered but were determined to not be as economical as the two column piers. The pile bents could not be economically configured to meet the owner's vessel collision requirements and the hammerhead piers required a lot more material than the two column piers. In order to strengthen the columns for the taller piers, a cross strut is added at a height of 40 feet from the top of footing in piers 55 feet and taller. Keeping the cross strut at the same elevation regardless of pier height maintained consistency in the rebar cages, formwork and concrete pours. The pier columns in the 3-span navigation unit are 6 feet square while the remaining columns are 5.5 feet square.

Fig. 6 Pile Installation

All piers located in a water depth of 2 feet or more were designed for a 200 kip impact from a drifting barge. The vessel loading requirements for an aberrant barge tow are shown in the table below.

Pier Type	**Distance from Centerline of Channel**	**Load (kips)**
Channel Pier	125'	2850
Channel Approach Pier	275' to 450'	2650
Approach Pier	451' to 850'	2500
Approach Pier	851' to 1100'	1350
Approach Pier	1101' to 1500'	800
Approach Pier	1501' to 1900'	300

Fig. 7 Vessel Collision Loads

The local scour depths due to the 100 year design storm event consistent with Katrina ranged from 11 to 26 feet at the main channel. The maximum water velocities and scour actually occur when the storm subsides and the surge flows back to the ocean.

The foundations governed by vessel collision loads of 200 kips (Piers 4 to 40 and 64 to 70) consist of 4-24 inch precast piles under each column. The compressive strength of the piles is 6000 psi. The 300 kip foundations (Piers 41 to 43 and 62 to 64) maintain the same footing size but use 4-30 inch piles with a compressive strength of 8500 psi. The 800 kip foundations (Piers 44, 45, 60 and 61) utilize the same footing and pile configuration but include a strut at the top of footing to distribute the collision load between column foundations.

The next group of foundations all fit within a 25 foot by 116 foot perimeter but utilize different footing sizes and pile configurations within that perimeter to resist the required collision load. The 1350 kip foundations (Piers 46, 47, 58 and 59) utilize 6-30 inch piles under each column connected by a strut at the top of the footing. The 2500 kip foundations (48 to 50 and 55 to 57) are supported by combined footings under each bridge pier with a waterline strut connecting the footings. The total number of 30 inch piles in this foundation is 26. The 2650 kip foundations (Piers 51 and 54) have the same footing configuration but with a total of 33-30 inch piles. Finally, the 2850 kip channel foundations (Pier 52 and 53) use a solid footing of 25 by 116 feet with a total of 36-30 inch piles.

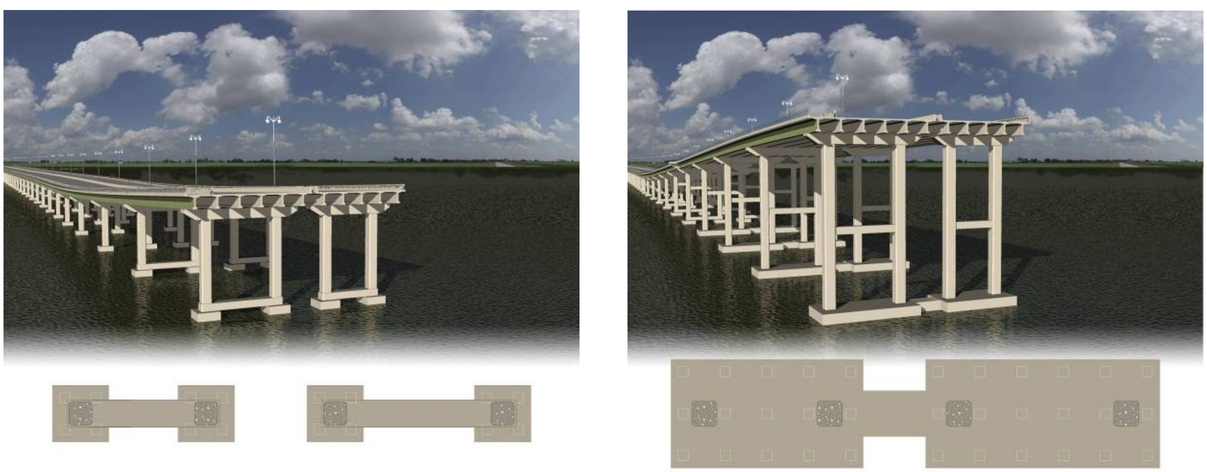

Fig. 8 Renderings of 800 and 2650 kip Piers

The vessel collision analysis was performed using two different models and software packages. The first model consists of a nonlinear, three dimensional analysis of the pier, foundation and the soil layers. The superstructure is modeled using equivalent spring supports. This model allows the derivation of the foundation stiffness matrix which is input into the second model. This global model is a three dimensional frame model of the piers and superstructure. The unit of the pier being impacted, as well as adjacent units, are represented in the model. The superstructure is modeled as a grid and the foundation stiffness matrix is input at the base of the piers. The superstructure essentially acts as a rigid diaphragm to help distribute the collision forces to adjacent piers that are not impacted. The distribution of the collision load is a function of the foundation stiffness of the impacted pier, the pier stiffness of the impacted pier above the foundation and the stiffness of the adjacent piers.

The analysis is iterative in nature due to the nonlinear response of the soil and the resistance of the collision load by multiple piers. The design criteria for the project required the structure to remain elastic under 90 percent of the collision load. The vessel load is applied in the global model and the displacements at each of the piers is compared to the results of the local models of the respective pier types. If the displacements differ significantly, the new foundation load is input into the local model and the analysis rerun. This is repeated until convergence is achieved.

NAVIGATION UNIT

The required vertical and horizontal navigational clearance is 95 and 150 feet respectively. To accommodate the required clearance, the navigation unit consists of a 3-span unit with a main span of 250 feet and side spans of 200 feet. The girders consist of 78 inch bulb-tees for the drop in and end span segments with haunched segments that vary from 6.5 to 12 feet over the piers. The end segments are 141 feet long and weigh 96 tons, the drop in segments are 132 feet long and weigh 87 tons and the haunch segments are 115 feet long and weigh 104 tons. All of the segments were delivered by barge from the precast yard. The 5 segments of each girder line are spliced together using 4-17 strand (0.6”ϕ) post-tensioning tendons anchored in the end segments. Both the rebar and the ducts are spliced within the 1.5 foot wide cast-in-place closures.

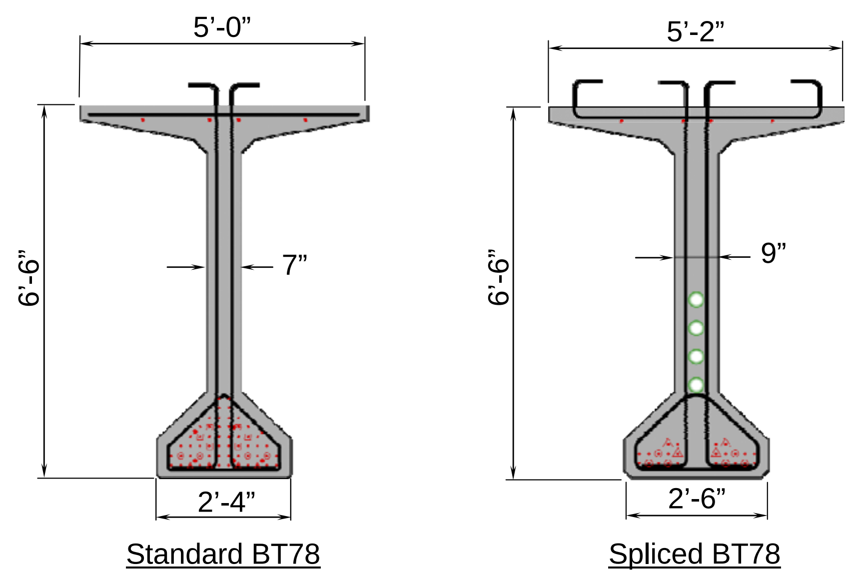

Fig. 9 Detail of Standard and Typical BT78 Girder

A web thickness of 9 inches is used instead of the 7 inch thickness for the typical 78 inch bulb-tee girder. This allows adequate clearance for the post-tensioning ducts. The typical 78 inch girder forms are used to cast the drop in and end segments by just spreading the forms apart and letting the top flange, web and bottom flange grow by 2 inches.

Fig. 10 Erection of the Navigation Unit

Cast-in-place diaphragms are located at each closure pour and at the piers. The pier diaphragms are post-tensioned with 3-5 strand (0.6”ϕ) tendons. The channel unit is supported by fixed pot bearings at each of the main span piers and sliding pot bearings at the end span piers. The height of the channel piers are sufficient enough that elastic shortening during tendon stressing and creep, shrinkage and thermal movements do not generate significant loads in the piers and foundations. A time dependent analysis accounting for the erection sequencing was performed to accurately account for all locked in forces and force redistribution due to creep and shrinkage.

The navigation unit girders were erected using steel falsework bents on each side of the main span piers to support the haunched segments. The falsework was supported by the permanent waterline footings. Strong-back hanger beams were attached to the drop-in and end segments to support them from the haunch segment until continuity was made.

CONCLUSION

This project is an excellent example of how design-build delivery, precast construction and a lot of hard work and cooperation on the part of the design, construction and owner team can result in successful fast-track delivery of major transportation projects. The design was completed ahead of schedule and the construction is currently ahead of schedule with the westbound bridge to be opened to two-way traffic on November 1, 2007. The use of precast construction and the development of an assembly line type production approach for both design and construction work combined to deliver this emergency reconstruction project in record time.

REFERENCES

1. Douglass, S., Chen, Q., Olsen, J., Edge, B., and Brown, D., "Wave Forces on Bridge Decks," FHWA Draft Report, April 2006.