LONG-SPAN STEEL GIRDER BRIDGES:

Stability Considerations for Design and Construction Engineers

BY: JARED G. FASICK, P.E. AND MERL E. STEIMER, P.E., GANNETT FLEMING, INC.

The new James Rumsey Bridge spans the Potomac River, connecting Maryland and West Virginia, at Shepherdstown, West Virginia. This new three-span 1,085-foot long curved steel haunched plate girder bridge, with a maximum span length of 425-feet and maximum web depth of 18’-4”, will replace an existing adjacent six-span, 1,020-foot long Wichert Truss bridge, which is one of only four known remaining in the United States.

The James Rumsey Bridge is situated in the heart of American history. It was at this location during the Revolutionary War that British and German prisoners were marched across the Potomac en route to Maryland military prison camps. During the Civil War the entire Northern Virginia Army withdrew from here into Virginia following the Battle of Antietam.

GROWING POPULARITY

Long-span steel plate girder bridge alternatives are increasingly being selected by Owners over more established long-span structure types such as box girders, arches, and trusses. Developments in fabrication capabilities within the United States, coupled with the economics of bridge construction, desired structural redundancy and a greater focus on bridge aesthetics for long-span structures, have resulted in an increased number of long-span steel girder bridges being constructed.

These long-span steel girder bridges, with spans in excess of 400-feet and web depths in the 20-foot range, are subject to pronounced out-of-plane rotations due to their scale during erection. Careful evaluation of girder stresses during erection, given the configuration of vertical and lateral erection bracing, as well as the rigidity of internal bracing elements, must be performed in the development of a successful long-span steel girder bridge erection plan.

SCOPE OF WORK

Gannett Fleming was retained by Advantage Steel & Construction, LLC, to develop the erection procedure for the James Rumsey Bridge, including: Temporary Bent and Temporary Tower design, Pier-jacking system design, Determination of bottom of girder elevations at temporary towers, Barge mounted crane stability evaluation, Temporary bearing stiffener design, and Causeway temporary bridge evaluation.

HEIGHTENED SENSITIVITY

Given the scale of the members involved, Design Engineers and Construction Engineers must have a heightened sense of awareness to compression flange stability prior to deck cure. Very low buckling stress limits due to extreme unbraced compression flange lengths for the first erected girder, exacerbated by Design Engineers pushing Code limits to generate more slender sections, mandate constant awareness of structural stability. Design Engineers, who are responsible for structural stability from the time erection is complete, can fail to properly consider compression flange lateral stability when arbitrarily utilizing diaphragm configurations identified by Owner standard drawings. This issue arises because of increased girder web depths. Diaphragm configurations, like that shown in Figure 1, without a top horizontal member, offer acceptable lateral flange stability for shallow depth girders. However, as shown in Figure 2, when girder depths become excessive, this diaphragm configuration offers minimal lateral flange stability. As such, the brace point that the Design Engineer considered without much forethought effectively is not a true brace point, thus permitting undesirable lateral compression flange deflections prior to deck cure. A diaphragm configuration with a top horizontal member, like that shown in Figure 3 should be utilized when web depths exceed half the girder spacing. This issue is one that owners are recognizing and addressing through revised standard drawings.

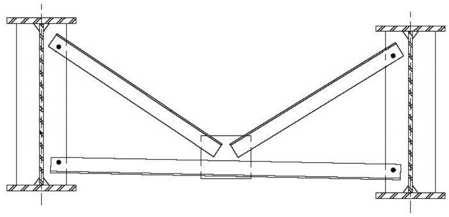

Figure 1. Typical diaphragm configuration for girders.

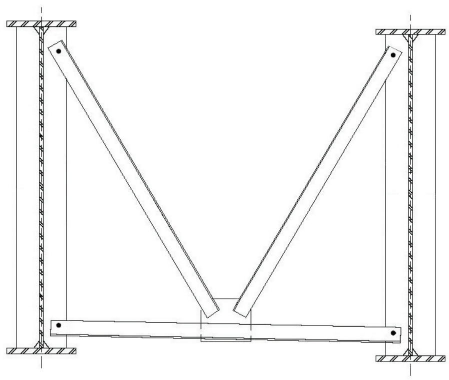

Figure 2. Flaw with typical diaphragm use on deep girders.

Figure 3. Correct diaphragm configuration for deep girders as utilized on the new James Rumsey Bridge.

Construction Engineers responsible for erection and control of compression flange stresses to prevent lateral-torsional buckling during erection assume significantly different risks than Design Engineers. Long-span steel girder bridges commonly replace and are located adjacent to existing truss bridges. Access to such a potential bracing element frequently results in ill-conceived lateral bracing details which a.) do not provide true lateral stability, and/or b.) do not permit vertical girder deflections without inducing lateral deflections.

Lateral-torsional buckling is best controlled by reducing distances between points of contraflexure, in effect controlling strong-axis moments, either with the use of hold cranes or the introduction of temporary towers. Given the spans generally associated with long-span steel bridges temporary towers provide a better means of reducing these distances because required hold crane capacities can become excessive. Temporary towers also permit the opportunity to introduce a brace point against wind forces, thus reducing wind stresses and lateral displacements during erection.

The following moment diagrams demonstrate the differences between the effective use of hold cranes and temporary towers in reducing distances between contraflexure points. Note the differences in the vertical forces applied and the differences in the distance between contraflexure points.

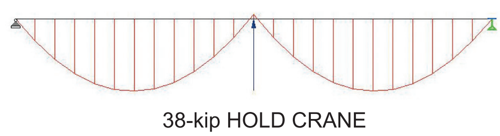

Figure 4. 250-foot span with a mid-span Hold Crane.

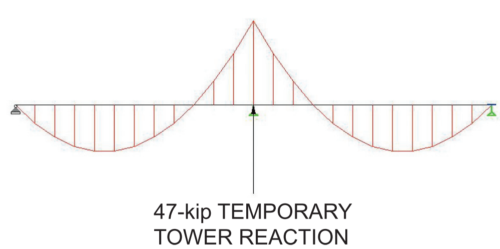

Figure 5. 250-foot span with a mid-span Temporary Tower.

Horizontal curvature of girders and wind loading complicate not only design but also erection. However, sharply curved long-span girder bridges are highly unlikely and with the appropriate control of strong-axis moments, additional wind stress effects can be accommodated. The new James Rumsey Bridge has only minor horizontal curvature at the ends of Spans 1 and 3 which was not severe enough to significantly increase erection stresses.

ERECTION CONSTRUCTABILITY

In developing an erection procedure, thought must be given to the Contractor's preferred means and methods. All Contractors have their own techniques they choose to rely on in order to facilitate construction. However, all revolve around the basic concept of flexibility. Construction Engineers and Contractors build flexibility into bridge erection through the use of:

- Hold crane and/or vertical jacking capabilities at temporary towers to aid in making field splice connections, and/or
- Pier jacking or the like, for aligning bearing stiffeners and bearings at consecutively fixed piers, thus permitting girder erection regardless of temperature effects.

Conceptual erection methods presented in Contract Documentation that rely on drop-in erection, pier girder-segment balancing, and barge-mounted temporary towers are recognized by Construction Engineers and Contractors for their inherent constructability, stability, and safety issues. The most preferred and cost-effective erection will progress from one abutment to the other in a continuous manner. This eliminates temperature considerations required for drop-in erection and further facilitates field splice connection.

The erection procedure developed for the new James Rumsey Bridge proceeded continually from Abutment 2 to Abutment 1 and utilized temporary bents, temporary towers, and limited use of hold cranes to control unbraced compression flange lengths. Constructability was aided through the use of vertical jacking at temporary bents and pier jacking.

SUMMARY

The new James Rumsey Bridge was successfully erected from June to November 2004, and withstood the effects of Hurricanes Charley, Frances, and Ivan, as well as the resulting flood from Hurricane Ivan, which destroyed the construction causeway and two temporary bridges on the causeway.

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IBC 2005 PRESENTS LONGEST SINGLE SPAN BRIDGE IN THE WORLD:

Strait of Messina Bridge Project Highlights Plenary Session

BY: DAVID TEORSKY, ESWP

The 2005 International Bridge Conference will present a special plenary session on the Strait of Messina Bridge Project, which, when opened in 2012, will lay claim to the longest single span bridge in the world. This extraordinary project will connect Sicily to Southern Italy, will conduct 6 lanes for vehicle traffic (3 each way), and 2 sections of railway tracks, offering capacity for 6,000 vehicles per hour and 200 trains per day.

Stretto di Messina S.p.A., the governing organization for the project, anticipates creating greater production and commercial exchanges by bringing the two shores together. The Bridge will enlarge the marketplace by facilitating greater trade between companies and creating new business opportunities, promoting greater integration between the regional economies, including tourism.

The Strait of Messina Bridge deck is 3,666 meters long and 60.40 meters wide. The steel aerofoil is supported by multiple steel hangers bound to the cables at 30 meters intervals. The total weight of steelwork is 66,500 tons. The deck is formed by three boxes connected every 30 meters by cross beams spanning between the hangers. It carries a pair of rail tracks in the center and a triple carriageway with an emergency lane on each side. A service road is positioned below the level of the remainder of the deck.

The two towers are over 380 meters high and stand in the Sicilian and Calabrian shores. The lamellar structure is made of high strength steel with a thickness of over 60 mm. Each tower has two legs with a diamond cross-section of 16 x 12 meters, connected by four horizontal crossbeams 17 meters high and 4 meters wide. Each leg is vertically composed by 21 sections 17 meters high and a top saddle for the main cables. The towers support the load of the two pairs of cables, equal to 102,500 tons on the tower in Sicily and to 98,800 tons on the tower in Calabria. Their aerodynamic performance has been optimized in the wind tunnel. The towers are built on round concrete plinths, with a diameter of 55 meters in Sicily and of 48 meters in Calabria. The first section of each leg is cemented at 12 meters depth into the foundation. The total weight of each tower is 56,000 tons. The suspension system is the "backbone" of the bridge and it is composed by two pairs of steel cables at the distance of 52 meters. Each cable, formed by thousands of wires, has a diameter of 1.24 meters after the compaction and is over 5,000 meters long between the anchor blocks. In particular, the cables length in the central span is 3,370 meters, while the side spans cables are 1,020 meters long in Sicily and 850 meters long in Calabria.

In the central span the four cables are formed by 88 strands with a diameter of 13.5 cm, for a total number of wires equal to 44,352. The high strength steel wires with a diameter of 5.38 mm are galvanized by hot dipping and surface treated to make them corrosion resistant in order to protect the cable coat against chemical and environmental factors. The total weight of wires is 166,800 tons. The cables of each pair are linked together by clamps every 30 meters and multiple hangers link the cable clamps to the deck to hold it up.

Mr. Pietro Ciucci, CEO and Giuseppe Fiammenghi, Chief Technical Officer of Stretto di Messina S.p.A., will present this special session for an early look into this world-class bridge project. The session will be presented on Tuesday June 14 at 11:00am, during the 22nd Annual IBC, at the Hilton Hotel, Pittsburgh, PA.

(*Specificiations* Source: *www.strettodimessina.it)*

A BRIDGE TOO NEAR

BY: PETER J. VANDERZEE AND JAMES D. COOPER, P.E., LIFESPAN TECHNOLOGIES

With apologies to Cornelius Ryan for the title twist on his 1981 book: "A Bridge Too Far", this article will discuss the growing pressure for infrastructure renewal (with a focus on highway bridges) and how the taxpaying public is shouldering a presumed financial burden supported by fuzzy logic. Mentally crossing this "bridge" requires some basic knowledge about how civil engineers design infrastructure and why bond rating agencies are concerned about growing debt levels to meet the anticipated infrastructure financial challenge. In recent years, the collision of AASHTO, GASB34, NBIS and structural health monitoring (SHM) has created more than alphabet soup; these four acronyms are reshaping the debate about what infrastructure really needs fixing, when, and how much it will really cost.

There is ample, reliable evidence in various reports, studies, books, articles, testimonies, and debates that political entities of every level in the United States have under-funded infrastructure for decades. This problem is significant (trillions of dollars), is gaining more and more attention, and won't be corrected without significant taxpayer pain and suffering. But, despite the alarms sounded by smart, forward thinking, rational experts, our bridges are not falling down on a monthly or weekly basis. In fact, it is generally acknowledged that our bridges are among the safest, if not the safest in the world. So, given the generally perceived magnitude of our infrastructure problem, could there be a "disconnect" between reality and perception of just how bad this problem really is?

"Because of carefully considered and conservative design protocols in past years, structure owners now have a path to safely extend the life span of existing structures."

As most of us are painfully aware, we continue to spend beyond our means at the Federal level. Ongoing Federal deficits and un-funded mandates will continue to drive local and State tax increases or spending cutbacks, since balanced budgets at the State and local level have legal imperatives. Recognizing this fiscal trend, when coupled with increasing demand for infrastructure investment, the Governmental Accounting Standards Board (GASB) adopted Statement #34 in 1999, requiring public entities to accurately account for and assess the condition of their managed infrastructure and to develop long term financial plans for its renewal or replacement. In essence, Statement #34 set in motion a process for improved Asset Management, long term planning, and communicating the impact of infrastructure renewal to bond rating agencies and the taxpaying public.

Prior to Statement #34, public entities typically managed their infrastructure on a short-term basis (fix it if it's broken), essentially hoping for the best in the long-term. This management approach resulted in the potential for chaotic fiscal swings (it's broken and we must fix it). By requiring more accurate assessments of asset condition, more rational, detailed infrastructure expenditure plans were a natural by-product, ostensibly allowing taxpayers and the bond rating agencies to fully appreciate the risks and implications of long-term infrastructure funding needs for individual jurisdictions. Unfortunately, despite all the benefits of increased information and transparency, funding plans and multi-million dollar decisions are still based on subjective asset condition assessments, not the precise, accurate measurements and evaluation techniques the public might expect.

Aging infrastructure has been an issue for decades and, short of spending a lot more taxpayer money, the problem will continue to get worse, not better. Decades ago, a few high profile bridge failures prompted the Federal Highway Administration (FHWA) to develop and put into practice an asset condition assessment protocol called National Bridge Inspection Standards (NBIS) that are contained in the the National Bridge Inspection Program (NBIP). Each State DOT and some enterprising private contractors developed a cadre of bridge inspection specialists whose responsibility it is to physically inspect all 580,000 plus bridges in the U.S. on a biennial basis – more often if warranted by condition. As a result of this massive and ongoing effort, approximately 90,000 bridges have been declared "structurally deficient" and carry reduced load ratings that are "posted" to provide a higher margin of structural safety for the motoring public. For many posted bridges, commercial traffic has to contend with costly and time-consuming detours to avoid overload conditions, with the unintended but unavoidable consequence of collateral damage to secondary bridge structures, increased traffic congestion, and more air pollution.

To be fair, increased traffic, larger loads, and higher speeds over the past several decades have caused greater stresses on bridges than designers initially anticipated. Consequently, real physical damage has resulted. As an example, the State of Oregon is currently dealing with a multi-billion dollar bridge replacement program, despite 30 plus years of NBIP inspections. However, after decades of inspection experience and studies to assess the efficacy of the NBIS inspection protocol, the FHWA recently concluded that the NBIS inspection process provides too much inconsistent, subjective information. Therefore, when considering the conservative nature of structural/civil engineers who must interpret this subjective inspection data and make important decisions regarding load carrying capacity, the actual number of structurally deficient bridges may be far less than is currently presumed. Given that conclusion, it is important to recognize there is no finger to point or blame to assign. Engineers are trained to be conservative and because they err on the safe side, bridges are not falling down every week. But, the forces of engineering conservatism have now run squarely into cold, hard fiscal reality - we simply can't afford to fix all 90,000 structurally deficient bridges.   Now what?

This problem, like most complex issues, has subtle nuances. First and most importantly, subjective information simply cannot support objective decision-making. Visual inspection of bridge condition is simply not sufficient to support major financial investments. Multi-million dollar decisions should be supported by more objective information, not "eyeballs and estimates". The good news is that commercial technology is now available to provide the essential, objective information needed to support these multi-million dollar decisions. The bad news is that few asset owners have adopted these new technologies.

"...that bridge replacement program that appeared to be 'too near' may actually be 'too far' away to worry about."

Second, while the conservative nature of structural/civil engineers has served us well in past decades, the conservative design protocols and analytics of the American Association of State Highway and Transportation Officials (AASHTO) might be reconsidered in the light of commercially available precision measurement technologies which can provide real-time, objective information on asset performance and condition, simply not available in prior decades. Given better information on structural condition, the relevant question is this: "Can existing structures be operated safely beyond their initial design limits, utilizing the inherent factors of safety that still remain?" That question is worth consideration given today's financial constraints, but operating a structure beyond its initial design limits is only defensible considering the liability if owners and their engineers carefully and methodically monitor structural performance on a real-time basis. There is no defense for not being judicious.

To put a metric to this issue, consider the following: 75% of the nearly 175 bridges tested over the past 15 years by a U.S. based structural analytics company were found to be capable of safely carrying more load than their posted ratings, some substantially more. While this confirms the overall conservatism caused by a subjective asset condition assessment process, it also calls into question the presumed urgency for near term repairs or replacements and the planned expenditure of taxpayer funds. One has to ask: "Is our infrastructure problem less of a problem than we originally thought?" Most distressing however, 5% of the tested bridges had safe load carrying capacity lower than posted limits. Who wouldn't agree to undertake a serious effort to more objectively assess those structures determined to be in worse condition than initially thought, even monitoring their condition on a real-time basis, if necessary? This real-life data is significant, not only because 80% of the bridges had load carrying capacity different than that determined subjectively, but it shows that owners can now objectively determine priorities for infrastructure expenditure and, at the same time, diminish political influence in the budgeting and appropriation process.

The management methodology that is gaining widespread acceptance to address issues like those described above is called Asset Management. One of its key building blocks is termed "asset assessment," a rational, objective process for determining asset condition. For the past decade, the FHWA has been touting an Asset Management scheme to State DOT's and other organizations with significant transportation infrastructure assets. But, state-of-the-art management of infrastructure assets is only possible with precision measurements, allowing accurate, objective asset condition assessment. For public executives who are responsible for infrastructure assets, the short phrase in vogue today is: "Measure to Manage". This phrase conveys the message that objective measurements are essential to properly manage a portfolio of large civil assets throughout their life cycle.

So how do we sort this all out? What suggested actions make sense for State and local Executives who have responsibility for managing large civil assets, facing the dual problems of decaying infrastructure and budgets that won't support anything but emergency spending?

First, it is essential to augment subjective asset condition assessments with objective asset condition assessments to support a 21st Century Asset Management Program. For bridges, this can be accomplished by adopting the latest analytical technologies to measure load carrying capacity and, for those bridges that have significant structural problems or known defects, implementing a real-time monitoring program. This new monitoring technology uses sensors to capture relevant data on structural elements of concern, sends information over the Internet to the asset owner's engineers, and allows decisions on repair and replacement to be made more objectively and "just in time" to optimize life cycle costs. These technologies generally cost less than two year's interest on a bond issued for asset replacement, providing a robust return on investment. Extending the useful life of a major civil asset two or more years has a substantial effect on life cycle cost and an already tight budget, not to mention the positive effect of delaying potential tax increases.

Second, senior executives in the public sector must insist on clarity and certainty of information for decision-making, not possibilities or guess-timates. Recognizing that engineers were trained to be conservative and follow prescriptive design and asset condition assessment protocols, they should be encouraged to research and implement promising new technologies that can provide the precision measurements necessary to allow objective decision-making that drives lower life cycle costs.

"Utilizing today's cost effective, precision measurement technologies to provide objective condition assessments, long-term structural monitoring can be the catalyst for optimizing Asset Management programs."

Third, asset owners must educate their engineering and technical staff about the fiscal realities they face. Once the technical staff accepts that their overly conservative nature is not always consistent with real-world fiscal constraints, better 21st Century Asset Management is just around the corner. And that bridge replacement program that appeared to be "too near" may actually be "too far" away to worry about.

SUMMARY

In summary, because of carefully considered and conservative design protocols in past years, structure owners now have a path to safely extend the life span of existing structures. Utilizing today's cost effective, precision measurement technologies to provide objective condition assessments, long-term structural monitoring can be the catalyst for optimizing Asset Management programs. Given a significant long-term funding crisis, taxpayer push-back, and increased financial transparency, adoption of these technologies will provide substantial value to those who are willing to embrace them.

Peter J. Vanderzee is President and CEO of LifeSpan Technologies, and Atlanta based structural health monitoring technology company. His systems are used by both public and private entities to inspect bridges, parking garages, buildings, pipelines, stadiums, cell/broadcast towers, and other large civil structures.

James D. Cooper, P.E., is on the Board of Advisors of LifeSpan Technologies. He is a bridge technology consultant and is a member of the International Bridge Conference (IBC) Executive Committee.

CRANBERRY CONNECTOR

Receives ACEC/PA Honor Award

BY: ARTHUR G. HOFFMANN, JR., P.E.,
GANNETT FLEMING

The Cranberry Connector, which was designed by Gannett Fleming, an international planning, design, and construction management firm, has received an Honor Award in the Transportation Category in the American Council of Engineering Companies of Pennsylvania's (ACEC/PA) 2005 Diamond Awards for Engineering Excellence Competition. In addition, this project was a finalist at the ACEC National competition.

Gannett Fleming designed the Connector for the Pennsylvania Department of Transportation (PennDOT) and the Pennsylvania Turnpike Commission (PTC). The Connector, located in Cranberry Township, PA, provides the much-needed link between Interstate 79 (I-79) and the Pennsylvania Turnpike, integrating the diverse transportation networks of PennDOT and the PTC. The result was a tremendous increase in traffic mobility and passenger safety.

Cranberry Township grew by more than 37 percent between 1990 and 2000, while U.S. Route 19 and Route 228 experienced rapid retail and commercial growth. Prior to the Connector, drivers wishing to travel between I-79 and the Pennsylvania Turnpike had to use Routes 19 and 228. The Connector reduced traffic from 85,000 to 57,000 average daily traffic along the Route 19 Corridor, as well as cut truck traffic on local roads by 75 percent.

Funding shortfalls delayed the project in the mid-1990s until value engineering was used in 1997 to trim $16 million off of the project's overall cost. The most significant outcome of this effort led to the use of the existing I-79 southbound lanes as the collector-distributor roadway, the first in western Pa. The effort saved three miles of roadway reconstruction and limited access ramp reconstruction, as well as minimized the need for right-of-way acquisition. In addition, this effort significantly reduced the project footprint and associated environmental impact.

The consideration of numerous alternatives and challenges led to the development of a phased construction plan, as well as project completion one month ahead of schedule at a cost that was $1 million under budget. The innovative construction plan ensured traffic was maintained on major and secondary routes throughout construction and allowed the project to move forward while necessary tolling studies were completed. In order to provide for free flow traffic conditions between I-79 and the Turnpike, mainline and electronic tolling was implemented.

Throughout design and construction, Gannett Fleming coordinated with PennDOT and the PTC, both of which have significant responsibilities for design, construction, and maintenance of transportation infrastructure. The Cranberry Connector formed a unique partnership between these two organizations that offers insight into advancing a major project between two distinct agencies and has set a high standard for similar future projects.

Fig.1 - Hoover Dam and Rendering of Completed Bridge

NEW COLORADO RIVER ARCH BRIDGE AT THE HOOVER DAM

BY: DAVID GOODYEAR, P.E. S.E., T.Y. LIN INTERNATIONAL; BONNIE KLAMERUS, P.E., FHWA CENTRAL FEDERAL LANDS; ROB TURTON, P.E. S.E., HDR ENGINEERING, INC.

INTRODUCTION

A dramatic new concrete arch is joining the setting of the historic Hoover Dam, spanning the Black Canyon between the States of Arizona and Nevada, USA. The 1,060 feet arch will be the 4th longest concrete arch in the world, and the longest in North America. The distinctive design combines steel and concrete components in order to optimize construction and structural performance. This will be the first arch structure of this scale to combine a composite steel deck with a segmental concrete arch and spandrels. The design is also unique in its use of steel Vierendeel struts between twin concrete arch ribs – a feature that both speeds construction and adds ductility to the lateral framing system for extreme seismic loads.

A project team of five US government agencies, led by the Central Federal Lands office of the Federal Highway Administration (CFL) is developing a highway bypass to the existing US93 roadway over Hoover Dam, shown in Fig 1. The existing highway route over the Dam mixes the throng of tourists for whom the Dam is a destination, with heavy highway commercial trucking. The blend of these two uses creates hazard and hardship for both. The mix of traffic is an added security burden for the Bureau of Reclamation, which operates Hoover Dam.

PROJECT DEVELOPMENT

A consortium of firms working under the moniker of HST (HDR, Sverdrup, and TY Lin International) teamed with specialty sub-consultants and CFL to deliver the final design for about 1.5 miles of approach roadway in Arizona, 2.5 miles of approach roadway in Nevada, and a major 2,000 foot long Colorado River crossing about 1,500 feet downstream of the historic Hoover Dam.

CFL's formation of both a Design Advisory Panel (DAP) and a Structural Management Group (SMG) as advisory groups for the design resulted in key input during the design process.

Bridge Type Screening Process:

By selecting an alignment so close to Hoover Dam, the new bridge will be a prominent feature within the Hoover Dam Historic District, sharing the view-shed with one of the most famous engineering landmarks in the US.

> **"This will be the first arch structure of this scale to combine a composite steel deck with a segmental concrete arch and spandrels."**

CFL decided to use information developed for prior studies along with new information developed by the design team in an initial Type Screening Process. This Type Screening process was developed to consider policy-level criteria as a first litmus test on bridge types that should proceed to a more formal type study. In the end, the deck arch concept was the selected bridge type.

Six deck arch alternatives were developed to the point that general quantities and construction methods could be established for pricing purposes, and were then reviewed and rated by both the DAP and the

SMG based on architectural and technical criteria, respectively. The DAP expressed a preference for simplicity, and the SMG criteria were similar to those used for the Screening Study – inspection, complexity, vulnerability, construction cost and duration, and serviceability. An integrated ranking was developed to combine the SMG ranking, DAP rating, and cost and schedule estimates. The selection of the Concrete Composite alternative was made by the Executive Committee, comprised of the operations chiefs from the five Agencies.

MAJOR FEATURES

The final form of the twin rib framed structure shown in Fig. 2 was dictated by the engineering demands on the structure. It was initially assumed that earthquake would control the lateral design of the bridge, but wind studies resulted in wind dominating the lateral force design.

Fig. 2 - Final Design Solution

Arch Framing:

The 10,000 psi concrete arch is an efficient element for gravity loads in its final form. Two design aspects favored a twin rib layout for this arch. The first is one of practical construction. A single box would be 65 feet wide, and weigh approximately 10 tons per foot, which would rule out a precast segmental option. The second is the performance under extreme lateral forces. Initial geophysical studies indicated the potential for a very high seismic design basis. A single arch rib left no opportunity for tuning stiffness or providing for frame ductility, whereas twin ribs provide an excellent means of creating ductile Vierendeel links that could otherwise fully protect the gravity system of the arch. Thus a twin rib arch framing system was selected (Fig. 3).

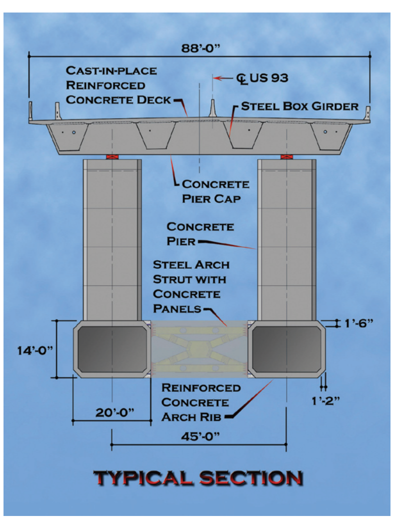


Fig. 3 - Typical Section

Arch Framing:

The composite superstructure was selected for speed of erection and to reduce the weight. The spandrel spacing was controlled by the concept of erecting the bridge using a highline (tramway) crane system. Above 50 tons, there is a jump in highline cost, so the spans were set to limit the steel box sections to 50 tons, which resulted in a 121 foot span. This span also allows steel girders to be set within the range of most conventional cranes, should an alternative erection system be selected. The statical system includes sliding bearings for the short, stiff piers over the arch crown, which minimized large secondary moments in these piers from creep deflections of the arch, and produced a more even distribution of longitudinal seismic forces among the piers.

Pier Cap Framing:

The integral cap framing (Fig. 4) was selected, both for aesthetics and to develop the diaphragm action of the deck used to avoid lateral bracing of the spandrel columns. Concrete was selected to avoid the higher maintenance and inspection costs associated with a fracture critical steel cap.

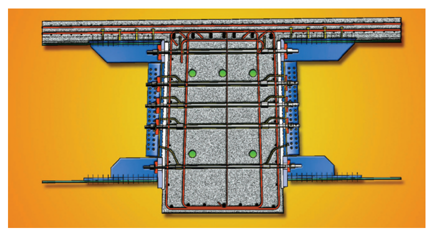


Fig. 4 - Integral Cap Connection

Open Spandrel Crown:

An open spandrel crown was selected over an integral crown to avoid an abrupt, mechanical looking connection at the crown. Equally significant was the high rise of the arch. When studied in either concrete or steel, an integral crown solution looked blocky and massive, and ran counter to the architectural goal of lightness and openness.

Cross-Section Form:

The first natural frequency of the arch system is over three seconds – a range normally reserved for flexible, cable-supported structures. Since wind forces dominated the lateral load design, shape became a primary design issue.

The tallest of the tapered spandrel columns is almost 300 feet tall. Wind studies considered drag and vortex shedding on the main structural sections exposed to the long canyon fetch from over Lake Mead. Substantial advantage was gained both in terms of vibration and drag by chamfering the corners of the columns and the arch.

CONSTRUCTION METHOD

The dead load design is dominated by the assumed construction scheme. The design team and owner agreed that a complete and detailed erection procedure should be shown on the plans. This approach will avoid long review times often associated with erection of structures this size, while reducing the risk that the contractor would overlook erection requirements critical to the performance of the final structure.

Two practical erection methods could be used to erect this arch. One is a simple cable-stayed cantilever erection (Fig. 5). The second is the use of temporary stay truss diagonals, erecting the arch, deck and spandrels as a cantilever truss (Fig. 6). The simple cable-stayed method provides the most conservative method, in that arch geometry can be controlled and corrected at each step of construction with stay and traveler settings. This method also allows the most flexibility for closing the arch without affecting the geometry of columns and deck since they are not placed until after closure. Both precast and cast-in-place methods are permitted for the arch and spandrel columns. The contract allows alternative methods of erection, but only the method shown on the plans is engineered for the contractor. All equipment and ancillary temporary works are also to be designed by the contractor.

Fig. 5 - Stayed Arch Erection

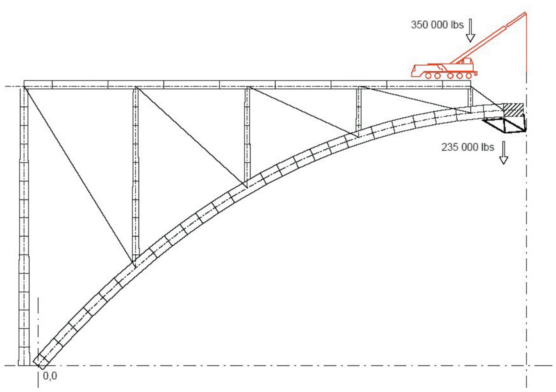


Fig. 6 -Alternative Erection Scheme

CONCLUSIONS

The commission from the DAP was to create a landmark bridge demonstrating the same design excellence that the designers of Hoover Dam exhibited. The bridge adheres to the adage that form follows function. Expanding the basis of design beyond the traditional concrete or steel solutions, designers used both concrete and steel efficiently to create the subtle, graceful crossing of Black Canyon that respects the grandeur of Hoover Dam, yet has its own identity. It is anticipated that the completed bridge will be open to traffic in 2008.

Documentation and progress may be tracked on the project website, www.hooverdambypass.org.

Fulton Road Bridge Replacement, Metro Parks Zoo, Cleveland, Ohio

Ford City Bridge Replacement, S.R. 0128, Sec. 012, (over the Allegheny River), Ford City, Pennsylvania

A FRESH APPROACH TO BRIDGE DESIGN'S NEW CHALLENGES

BY: JOHN DIETRICK, P.E.
MICHAEL BAKER JR., INC.

As bridge engineers gather from around the world for the 22nd International Bridge Conference, they do so as a professional group facing new challenges in an ever-evolving industry. Both designers and owners find themselves confronting the converging issues of an aging bridge infrastructure, re-directed public funding, and increasing demands from the public to participate in how these needs are addressed. The detailed design of a bridge is often the least complicated aspect of a project.

As engineers, we are well prepared for the technical challenges of bridge design, but maybe not as well for the sometimes difficult realities associated with today's transportation projects, such as working with the public, understanding environmental commitments, and appreciating the financial concerns of owners. Many bridge engineers indeed find themselves in unfamiliar territory.

"Providing a fresh approach to bridge design that leads to safer, more practical, more economical and longer-lasting solutions is our ultimate goal."

Recent experience at Michael Baker Jr. Inc., (Baker), headquartered near Pittsburgh, PA, has provided engineers with on-the-job training in designing bridges effectively in an industry of increased environmental oversight and public participation. Embracing this training challenges the bridge engineers at Baker to step outside the traditional bounds of their technical schooling. Likewise, recent experience at Baker developing context-sensitive solutions for a number of projects, including several now brought to completion, provide lessons learned in an effort to hone skills and better serve clients in today's complex design environment.

APPRECIATING THE LIFE-CYCLE APPROACH TO BRIDGE DESIGN

Working closely with public stakeholders on a wide range of bridge projects provides a better understanding of what public stakeholders consider important to the success of major transportation projects.

Owners represent the most fundamental stakeholders, as they hold the keys to new public projects and stand responsible for lifetime maintenance and protecting the public's safety. The importance of incorporating a life-cycle approach to the design or rehabilitation of a bridge is demonstrated by the number of structurally deficient and functionally obsolete bridges in the nation's inventory and the ever-present competing interests for funding. Design decisions and recommendations now routinely consider more than "first cost"—all reasonable means to reduce owners' long-term maintenance costs are explored, including:

- Using precast and prefabricated bridge systems that result in higher quality, better durability and shorter construction periods.
- Proactively avoiding maintenance-prone and fatigue-prone details that plague a bridge's useful life and, over time, drain an owner's resources.
- Using high-performance bridge materials including steel, concrete and fiber reinforced polymers (FRP).

Baker is at the forefront of promoting advanced materials and construction techniques for bridges. The Ford City Bridge, designed by Baker in the late 1990s for the Pennsylvania Department of Transportation, incorporates High Performance Steel (HPS) in the flanges of the 14-foot-deep girders, and was the first such application of HPS in the U.S. We've also designed major precast concrete bridges with High Performance Concrete (HPC), including the Route 52 Causeway/Bridge between Somers Point and Ocean City, NJ, which when completed will consist of over a mile of precast concrete segmental bridge. The advantages of high-performance materials to provide lighter and stronger bridges will stand the test of time and protect owners' long-term investments.

Embracing a life-cycle approach to the preservation, enhancement and replacement of bridges makes for better stewards of the public trust. This is the spirit of the Federal Highway Administration's new "Highways for Life" program, a proposed pilot program with three main objectives: to improve safety, reduce congestion due to construction, and improve highway quality. When enacted, this major new initiative will promote innovative approaches and new technologies that will enhance highway quality, from better construction techniques that minimize construction duration and impacts to the public, to improved durability for minimized long-term maintenance. Bridge designers will play a critical role in the success of the Highways for Life program.

BETTER BRIDGE ENGINEERS THROUGH CONTEXT-SENSITIVE DESIGN

Ultimately, the real winner in this holistic approach is the traveling public, who benefit from safer and more economical bridges, and smarter investment of taxpayers' dollars. There are many benefits to the designer as well. Working closely with public stakeholders helps define what a good bridge design is in the eyes of those not concerned with the engineer's calculation sheets. Today's savvy, customer-focused designers have learned to embrace a context-sensitive approach, which focuses on the unique needs of each bridge in the context of its specific environment.

"Our challenge is to perpetuate and improve the evolving way engineers do business in the public arena."

The context-sensitive approach is often misunderstood as a means to interject aesthetics and visual enhancements, occasionally at the expense of more practical project concerns. Context-sensitive solutions, when properly applied, actually lead to more effective designs that can even save money. One example is the recently completed Wintergreen Gorge Bridge, which received the 2003 ABCD Outstanding New Major Bridge Award. This structure, built over the environmentally sensitive Wintergreen Gorge near Erie, PA, was destined for a "signature" design based on early public sentiment. Through extensive preliminary design, Baker concluded that deep steel plate girders, using high-performance steel, minimized construction impacts to the gorge and ultimately provided more open and pleasing aesthetics. When communicated to the public fairly and openly, stakeholders were able to reach informed consent on the girder type structure, saving the owner millions in construction dollars. Clearly, the best solutions are not always the most artistic or elaborate design.

Wintergreen Gorge Bridge, S.R. 4034, Section A80, Erie County, Pennsylvania

To leverage the benefits of context-sensitive design, project managers and bridge designers must take an active role in the public outreach process. This has two distinct benefits. First, it allows designers to understand and appreciate first-hand concerns of the end users, which leads to transitioning those concerns to integral project goals. It also puts the design leadership at the disposal of the key stakeholders. This approach is appreciated by clients and stakeholders, and often helps facilitate consensus building by providing ready access to the structural engineering behind proposed concepts.

As an example, Baker bridge engineers in Cleveland, Ohio, have been working closely with the Cuyahoga County Engineer's Office to provide a context-sensitive solution in a very unique environment. The Fulton Road Bridge, which crosses directly over the Cleveland Zoo, is a concrete arch bridge that is quickly approaching the end of its useful life after 80-plus years. Historically, a "lowest first cost" approach might have dictated that the arch bridge be replaced with a more standard, less aesthetic structure type. The context-sensitive approach, however, has focused on three important aspects of the bridge that suggest a different solution. First, the existing arch bridge, with its unique proximity to the public, represents a symbolic landmark to the public that would be lost if replaced with a standard overpass-type bridge. Second, costs associated with frequent maintenance over the zoo would be costly, and long service-life is preferred to defer replacement as far into the future as possible. Third, construction impacts to the operations of the zoo, which receives over a million visitors per year, have the potential to be significant and rapid construction is strongly desired. These considerations, backed up by a public involvement process, led the County to select a precast, post-tensioned concrete deck arch bridge type, which Baker has currently carried into the final design phase.

CHALLENGES OF THE NEW DESIGN CODE

As the bridge community moves into the second half of the decade, another challenge will be faced by designers and transportation agencies—the full implementation of the new Load and Resistance Factor Design (LRFD) code. Baker's proficiency with the new code was endorsed by the FHWA by our recent selection to develop and deliver the LRFD Superstructure Training Course (NHI Course No. 130081 - Load and Resistance Factor Design for Highway Bridge Superstructures). This selection followed similar training Baker developed for the FHWA for the NHI LRFD Substructure Training Course (NHI Course No. 130082A - LRFD for Highway Bridge Substructures and Earth Retaining Structures) which also included an evaluation and recommendations for modifications to the code. Full acceptance of the new reliability-based LRFD code, in concert with the context-sensitive approach, will ultimately lead to better, more efficient designs nationwide.

" ...designers and owners find themselves confronting the converging issues of an aging bridge infrastructure, re-directed public funding, and increasing demands from the public to participate in how these needs are addressed. "

MANY MORE LESSONS LEARNED

While many valuable lessons have been learned in the new bridge design environment, continued progress is essential. Baker's open, context-sensitive approach to design will be put to the test in Louisville, Ky., where the Kentucky Transportation Cabinet and the Indiana Department of Transportation will be delivering one of the largest transportation projects in the country. The $2 billion Louisville Southern Indiana Ohio River Bridges Project will require monumental coordination and outreach efforts, and anything short of a true context-sensitive solution will not meet expectations.

SUMMARY

Bridge engineers attending this year's International Bridge Conference find themselves wearing different hats and performing services they never thought would be required of the profession. Our challenge is to perpetuate and improve the evolving way engineers do business in the public arena. Providing a fresh approach to bridge design that leads to safer, more practical, more economical and longer-lasting solutions is our ultimate goal.

IBC 2005 BRIDGE AWARDS

The International Bridge Conference® in conjunction with Roads and Bridges Magazine, Bayer Corporation and Bridge design and engineering Magazine, annually awards five medals to recognize individuals and projects of distinction. These medals are named in honor of the distinguished engineers who have significantly impacted the bridge engineering profession worldwide.

*The **John A. Roebling Medal**, presented since 1988, recognizes an individual for lifetime achievement in bridge engineering.*

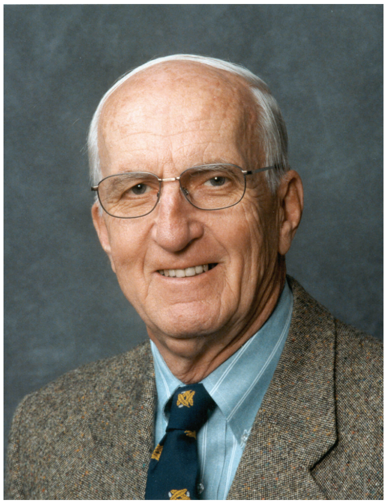
*The **George S. Richardson Medal,** presented since 1988, is presented for a single, recent outstanding achievement in bridge engineering.*

*The **Gustav Lindenthal Medal**, presented since 1999, is awarded for an outstanding engineering structure that is also aesthetically and environmentally pleasing.*

*The **Eugene C. Figg Jr. Medal** for Signature Bridges, presented for the first time in 2002, recognizes a single recent outstanding achievement in bridge engineering that, through vision and innovation, provides an icon to the community for which it was designed.*

*The **Arthur G. Hayden Medal**, first presented in 2003, recognizes single recent outstanding achievement in bridge engineering demonstrating vision and innovation in special use bridges such as pedestrian, people-mover, or non-traditional structures.*

John A. Roebling Medal



The John A. Roebling Medal recognizes an individual for lifetime achievement in bridge engineering. We are pleased to recognize Dr. John E. Breen as the 2005 recipient. **Dr. John E. Breen** holds the Nasser I. Al-Rashid Chair in Civil Engineering at The University of Texas at Austin. His prize winning research has been the basis for design and construction standards for structural concrete bridges and buildings in topics such as slender columns, hollow piers, reinforcement development and splices, strut-and-tie models, post-tensioned anchorage zones, and fatigue and durability of tendons and cable stays. He was responsible for design and model testing of the first precast segmental concrete box girder in the USA and was a principal author of the AASHTO Guide Specifications for Segmental Bridges. He has received 5 university and national awards for his teaching of structural concrete design. He is a co-author of the Wiley text, Reinforced Concrete Fundamentals.

630-FOOT JOINTLESS BRIDGE

BY: JOHN PERKUN, P.E.,
SAI CONSULTING ENGINEERS, INC.

INTRODUCTION AND DESCRIPTION OF PROJECT

One of the primary problems facing bridge engineers and bridge owners over the years has been the degradation of bridge structures due to failure of joints placed in the bridge to handle the normal thermal movements. Once the integrity of the joint is compromised, many problems can arise including water infiltration to vulnerable parts of the bridge structure, failure of the joint to provide the movement required, and damage to the deck or riding surface itself. This is especially true in climates subject to freeze-thaw cycles where water infiltration through a failed joint can cause dramatic problems to steel and concrete bridge elements alike. One solution to this joint failure problem has been to design bridges with no joints thus averting, to a great degree, problems as described in the previous paragraph. This, of course, provides challenges relative to how the movements of the bridge can be effectively handled and to provide longevity for the bridge structure. Since the movements of these jointless bridges cannot occur on the bridge superstructure, provisions for movement must be made at the ends of the bridges through the use of integral and semi-integral abutments.

One such challenge was put forth by the West Virginia Division of Highways for the replacement of an aging bridge in St. Albans, West Virginia. The bridge that carries U.S. 60 over the Coal River in St. Albans, West Virginia was programmed for replacement by the West Virginia Division of Highways (WVDOH) in the late 1990's. In 2000, the WVDOH retained SAI Consulting Engineers, Inc. to design a replacement for the existing 570-foot, five-span, riveted steel girder bridge. The existing bridge had four travel lanes and two 3 foot sidewalks. The existing superstructure consisted of three main girders with floor beams and stringers, was on a 38-degree skew, and utilized sliding plate expansion dams at the two abutments.

Bridge Name	Length	Span Arrangement
Lost River Bridge No. 1	666.1'	173.9' – 262.5' – 229.7'
US 220 Ramp Connector Bridge	615'	136'-171. 5'-171. 5'-136'
Edgewood Drive Bridge	586'	111.25'-111. 25'-140'-111.25'-111. 25'
Dumpling Run Bridge	543'	167'-209'-167'
Elizabeth Bridge	536'	163'-210'-163'
Sauerkraut Bridge	524.9'	154.2'-216. 5'-154. 2'

Table 1. West Virginia Jointless Bridges
(All Utilize Semi-Integral Abutments)

The replacement bridge would be wider than the existing bridge and would consist of four 12-foot travel lanes, a raised 4-foot center median, two 6-foot shoulder/bicycle lanes, two concrete parapets, and two 5 foot sidewalks (78'-7-1/2").

In accordance with West Virginia Division of Highways policies, bridges are to be designed with a minimum number or no joints at all. West Virginia has a growing list of jointless bridges. However, the bridges shown in Table 1 all employed semi-integral abutments. The challenge was in place—to design one of the State of West Virginia's longest jointless bridges and successfully incorporate integral abutments.

WEST VIRGINIA DIVISION OF HIGHWAYS DESIGN PHILOSOPHY FOR JOINTLESS BRIDGES & INTEGRAL ABUTMENTS

The West Virginia Division of Highways has standards for design and construction of jointless bridges and are contained in West Virginia Division of Highways Bridge Design Manual, Section 3.9 – Jointless Bridge Abutments. This standard provides design guidelines along with construction details for design of integral and semi-integral bridge abutments. The standards states, "Fully integral and semi-integral abutments shall be used whenever possible to eliminate deck expansion joints."

DESIGN PHASE

After preliminary design activities were undertaken it was decided to advance two steel girder bridges to the Type, Size and Location study phase of the project. The following is a summary of the two alternates advanced for further studies: 1. One bridge that would carry the entire proposed 78'-7-1/2" cross-section. This alternative would consist of a 530-foot-long, three-span, continuous steel bridge with skewed (38-degree) abutments and piers. 2. Two separate, parallel 39'-3-3/4"-wide bridges with perpendicular abutments and piers. Each bridge would be a 630-foot, three-span, continuous steel bridge. The use of perpendicular abutments and piers required these substructure units to be longitudinally offset by 30.5 feet.

	Alternate 1	Alternate 2
Bridge Type	Welded steel plate girders	Welded steel plate girder
Span Lengths	165'-200'-165' = 530'	195'-240'-195' = 630'
Girder Spacing	8'	8'
Girder Size	57" web with varying flange thickness	66" web with varying flange thickness
No. of Girders	10	8 total (4 each from EB and WB structures)
Bearings	High-load, multi-rotational bearings	Elastomeric bearing pads
Steel Type	AASHTO M270/Grade 50W/Grade HPS 70W	AASHTO M270/Grade 50W/Grade HPS 70W
Skew	38º	0º (Radial)
Abutment Type	Semi-integral	Integral
Pier Type	Four-column bent with concrete cap	Single-column with hammerhead cap

Table 2. Two Alternates Advanced for Further Study

The two bridges selected were very different from each other. Alternate No. 1 could be designed and built under the West Virginia Division of Highways criteria. The skew was not excessive and semi-integral abutments could be employed. The length of the bridge at 530-Feet was also similar to bridges already built by the West Virginia Division of Highways and shown in Table 1. The main detracting element to this alternative was the need to construct two large skewed piers in the Coal River that would require large cofferdams.

Alternative No. 2 was attractive because the skew could be eliminated and all of the substructure elements could be placed perpendicular to the bridge superstructure. The overall length of the bridge at 630-Feet was at the upper end of the length of jointless bridges undertaken by the West Virginia Division of Highways as shown in Table 1. However, the West Virginia Division of Highways had not undertaken the use of an integral abutment, for a bridge of this length.

Selection of Alternate:

The West Virginia Division of Highways selected Alternate 2 to advance to final design. The primary reasons for this decision are:

1. Elimination of the skew permitted the substructure elements to be placed perpendicular to the bridge superstructure.
2. Separate parallel bridge structures could more easily be phased into the construction sequencing of the bridge.
3. The pier construction was greatly simplified with the use of a single-column, drilled-shaft configuration. Disturbance to the riverbed would be significantly reduced.
4. Interference with existing deep foundations was eliminated by lengthening the bridge to avoid placing the new offset abutments on the existing abutment.
5. Previous experience with integral abutment bridges instilled confidence in the West Virginia Division of Highways that a 630-Foot bridge could be constructed.

CONCLUSION

In conclusion, the challenge that was presented by the WVDOH to design a 630 foot long jointless bridge was met successfully. Guidelines provided by the WVDOH and also their experience and willingness to "push the envelope" were crucial in putting together a successful project.

As this bridge ages the bridge will have to monitored to make sure it is accommodating thermal movements. Cracking and settlement of approach slabs, degradation of adjacent roadway pavements, cracks in the concrete deck, etc. will have to be analyzed to see if the integral abutments are working successfully.

The project went under construction in January 2004, and in the first week of January 2005 the westbound lanes of the new bridge was opened to traffic. Currently, the eastbound lanes are under construction and the project is on schedule for a December 2005 opening.