ADVANCES IN DESIGN, CONSTRUCTION, INSPECTION & PRESERVATION OF BRIDGES

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2A MAJOR BRIDGE DESIGN PROJECTS

Prefabricated Decked Girders for Accelerated Bridge Construction in Washington State

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Prefabricated bridge elements and systems (PBES) offers significant cost and time savings, improved safety, and convenience for traveling public. Precast/prestressed concrete decked girders are prefabricated bridge systems that are often used for accelerated bridge construction (ABC). Precast/prestressed decked concrete girders are composed of concrete I-beam, bulb-tee, or multi-stemmed girder with an integral deck that is cast and prestressed with the girder. A thin cast-in-place concrete slab with minimal reinforcement placed over the top surface is used for mainline bridges to improve the long term performance of precast decked bridges.

This paper describes the optimized cross sections of precast decked system for long span bridges with PBES/ABC consideration. Design, fabrication, transportation, construction of precast decked systems is investigated. This paper addresses factors such as the connections between adjacent units, performance of longitudinal joints, use of UHPC for closures, continuity for live load, skew effects, use of light weight concrete, and alternative details for traffic barrier on decked members. Companion analytical study for post-tensioned spliced decked girders is also presented.

I-405 Sepulveda Pass Widening Design-Build

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The $1 billion Sepulveda Pass Widening Project will add 10-mile high-occupancy vehicle (HOV) lane and improve supporting infrastructure on I-405 by widening lanes and shoulder to full standards from I-10 to U.S. 101. Key project features include removing and replacing Skirball Center, Sunset Boulevard, and Mulholland Drive bridges; realigning 20 entrance and exit ramps; widening 14 undercrossings; replacing six ramp structures; and constructing 18 miles of retaining and sound walls. The last of three bridges to be demolished and rebuilt, the Mulholland Drive Bridge is the most significant. These three bridges were originally built by Kiewit back in early 1960's. Kiewit/HNTB Design/Build Team began design/construction of I-405 Sepulveda Pass Widening Project in 2009 and they are scheduled to complete in year 2014. The $1 billion project broke ground on May 8, 2009.

Currently the largest budget design-build highway project in Southern California, the I-405 Sepulveda Pass Widening Project breaks the traditional model used to build highways in the State of California. Rather than using traditional design-bid-build method, the I-405 project uses design-build vehicle to deliver major highway renovation with potentially lower costs and reduced schedule while maintaining high quality.

The I-405 Sepulveda Pass Widening Project will add 10-mile northbound carpool lane on the San Diego Freeway (I-405) from the Santa Monica Freeway (I-10) to the Ventura Freeway (US 101). The Completion of the $1 billion project is projected for year 2014. This project will improve ramps, bridges, construct several miles of retaining walls, and also add sound walls. Specific improvements include:

- Removal and replacement of three bridges at Skirball Center, Sunset Blvd, and Mulholland Dr
- Realignment of 27 on- and off-ramps
- Widening of 13 existing overpasses/structures
- Construction of approximately 18 miles of retaining walls and sound walls.

I-405 was completely shut down for a weekend in July 2011 between Route 101 and I-10 to demolish southern half of the bridge. This unprecedented undertaking that made international headlines was completed ahead of schedule with minimal impact to City of LA.

2B ACCELERATED BRIDGE CONSTRUCTION

Design and Construction of the SR 99 Atlantic Street Bypass

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One phase of the SR 99 Alaskan Way Viaduct replacement project is the construction of the South Atlantic Street Overpass in the SoDo neighborhood of downtown Seattle. This structure will provide a vehicle and pedestrian crossing over SR 99 and a portion of the Burlington Northern Santa Fe railroad tracks. The bridge was designed by the Washington State Department of Transportation Bridge and Structures Office as a raised intersection with two independent alignments and 5 separate frames that are linked by four in-span hinges. When complete, the bridge will form a visually striking gateway into Seattle through an otherwise industrial area.

The central two frames of the bridge are composed of five foot deep cast-in-place post-tensioned box girders, each having six webs. These two frames meet at a nearly 90 degree 'T' intersection. Connecting to this central box structure are three frames or legs, each constructed of three lines of five foot deep spliced precast pre-stressed tub girders. The overall structure when complete will take the shape of a little 'h,' as the nick-name suggests.

The substructure consists of 5'-6" square columns on 80-100 foot deep drilled shafts. Two of these piers were constructed as a change order to the previous stage contract due to staging concerns. Construction of the overpass occurs in conjunction with the final stages of the replacement of the southern portion of the Alaskan Way Viaduct, and will occur simultaneously with construction of the new SR 99 bored tunnel. Substantial completion of this structure is expected by the end of 2013.

This presentation will cover preliminary design constraints, the structural and geometric challenges encountered during design and the on-going challenges of constructing this unique structure.

2C SEISMIC DESIGN CRITERIA

Performance Objectives and the AASHTO Guide Specifications for the LRFD Seismic Bridge Design

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In March 2009, the American Association of State Highway and Transportation Officials published the first edition of the AASHTO Guide Specifications for LRFD Seismic Bridge Design (SGS). Although currently limited to a single performance objective (i.e. "no collapse"), the SGS is a displacement-based design approach that can be modified to address other performance objectives such as "minimal damage" and "repairable damage." These performance objectives may allow for the more immediate use of a bridge after a larger seismic event. As the decision makers expect greater functionality of the transportation system after a large seismic event, designers are tasked with designing bridges to not just survive the design event but to remain operational thereafter.

Performance-based seismic design (PBSD) attempts to coordinate the decision making for bridge design with the seismic hazard, bridge response, and potential damage. That is, PBSD aims to provide decision makers and stakeholders with data that will enable them to allocate resources based on levels of desired seismic performance (e.g., minimal damage, repairable damage, no collapse). Although PBSD considers the uncertainty of the hazards, structural response and extent of damage, this presentation will focus on the engineering parameters (strain and deformation) to extent of damage in the earthquake resisting elements.

The Alaska Department of Transportation and Public Facilities, AASHTO and other agencies have been sponsoring research on PBSD. Although much work remains, the researched complete to date may help forecast the future of seismic bridge design specifications. Some of the specific topics that will be covered include:

- Earthquake load history effect on reinforced concrete column strain limits
- Methods to more accurately correlate inelastic strains to member deformations
- Methods for predicting the onset of reinforcing bar buckling in plastic hinge regions
- Strain limits for concrete filled steel pipes
- Nontraditional systems for addressing seismic demands (e.g., isolation bearings)
- Direct displacement based seismic design

The Importance of Considering Column Top Rotation in the Displacement of a Triple Friction Pendulum Isolators for Tall Column Structures

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Fletcher Waggoner, M.S., P.E. • *SC Solutions, Inc.*

The SR520 North West Approach replacement project will consist of 40 spans of isolated, elevated roadway. The design includes approximately 100 triple friction pendulum isolator bearings atop columns supporting the superstructure. A detailed ADINA model was generated, which used a nonlinear user-derived element for the isolation bearings, coupled in the two principal horizontal directions. During an earthquake, the column top motion causes the isolator base to rotate. The user-derived isolator element considers this rotational effect, which results in substantially more bearing displacement than if the rotation is neglected. If the column top rotation is not considered, the design displacement can be under-estimated, resulting in a bearing that is too small for the design seismic conditions. Other issues considered in the isolator element are velocity dependent friction, and vertical damping.

2D BRIDGE REHABILITATION

Hagwilget Suspension Bridge Refurbishment, Hazelton, BC

Jeff Mellor • *Buckland & Taylor, Ltd*

The Hagwilget Bridge—an 80 year old, single lane, suspension bridge spanning 460′ with severe corrosion of primary structural elements underwent substantial refurbishment in 2012. The presentation covers three aspects of the refurbishment.

- The replacement with live traffic of the 31 needle beams that support the truss and connect to the hangers.
- The un-wrapping, inspection and re-wrapping of 130′ of the main cable at 10 locations.
- The replacement of the upper plan gussets, which involved jacking the composite acting steel grating deck off the truss in 15 minute closure windows.

During the works 6 of the hangers were also removed and replaced for destructive testing to provide an indication of their current capacity. Currently the bridge is being re-coated and further steelwork replacement is anticipated for 2014.

Rehabilitation of Long Span Bridges

Christopher Ligozio • *KPFF Consulting Engineers*

The I-310 Hale Boggs Bridge across the Mississippi River, opened in 1983, was the first cable-stayed span on the Interstate Highway system. Damage to the stay cable sheathing pipes compromised the corrosion protection system, leaving the cables vulnerable to corrosion, and impaired service life. Although repairs were attempted during and following construction, they performed poorly, and failed to protect the cables' main tension element. Condition assessments and a rehabilitation study concluded in 2007, that 39 out of 72 cables were in critical need of repair. Based on a life cycle cost and risk analysis, it was concluded that replacement of all cables represented the best value. The design of the complete 72-cable replacement array considered many factors, and was the first of its kind in North America. Stay cable replacement was completed in November, 2012.

Bayonne Bridge "Raise the Roadway" Project

Chester Werts • *HDR Engineering*

The Bayonne Bridge, spanning the Kill Van Kull and connecting Bayonne, NJ with Staten Island, NY, is the third longest steel arch bridge in the world and was the longest in the world at the time of its completion in 1915. The Bayonne Bridge "Raise the Roadway" project is a comprehensive program to raise the clearance of the Bayonne Bridge over the Kill van Kull shipping canal which accesses lower New York harbor and the Hudson River. The main objective of the project is to provide a navigable route for the next generation of container vessels, with heights exceeding 200 feet, to one of the busiest port facilities in the world, the Port of New York & New Jersey. To achieve this goal, the Port Authority decided to increase the navigational clearance of the existing 1,652 foot long steel arch from 151 to 215 feet above mean high water and consequently to rebuild all the approach bridge structures. It is noteworthy to mention that all of this will be done, while still maintaining traffic in both directions across the bridge.

The design effort is a joint venture between HDR Engineering and Parsons Brinckerhoff, in which HDR is responsible for the design of the main span arch and approach superstructures, and Parsons Brinckerhoff is responsible for the design of the approach substructures, at-grade roadway, drainage and electronics. The superstructure type selected for the approaches is a segmental, precast, post-tensioned concrete box-girder, consisting of twin single-cell trapezoidal shaped box girders, one for the northbound and one for the southbound traffic with spans of up to 272 feet. The total length of all four approach structures is approximately 10,614 feet and is composed of a total of 52 spans. The substructure consists of multiple configurations of concrete piers using a combination of precast and cast-in-place construction, with either drilled shafts or micro pile foundations.

The presentation will give an overview of the design and construction of the Bayonne Bridge "Raise the Roadway" project and then focus on the design and construction aspects of the segmental approach superstructures. Discussion topics will include preliminary design decisions and the unique design aspects of the approach structures, as well as the many challenges that were encountered during the final design. Lastly, the presentation will discuss anticipated challenges that may be encountered during construction. Summary of topics include:

- Background for the decision to raise the roadway through rehabilitation of the arch.
- Overview of the construction steps necessary to raise the main span and to construct the approaches.
- Design criteria for the approach structures.
- Unique aspects to the design of the approach superstructures.
- Challenges in the design of the approach superstructure bridges.

3A MAJOR BRIDGE DESIGN PROJECTS

Bridgelation on the I-4/Selmon Expressway Connector Project

Morad G. Ghali, PE • *Atkins*

Kenneth C. Saindon, PE • *Atkins*

Bridgelation

bridg·e·la·tion *noun* [brij-ə-ley-shun]

: a feeling or state of great joy or pride that derives from working on projects composed almost entirely of elevated structure

The I-4/Selmon Expressway Connector is located in Tampa, Florida. The project consists of a 1.0-mile north-south elevated link with directional interchanges between I-4 and the Selmon Expressway, both major east-west corridors. The project significantly improves mobility of people and goods, providing exclusive truck-lane direct access to the port of Tampa to remove this traffic from the local streets of historic Ybor City. The Connector is one of Florida's largest Strategic Intermodal System projects, and also features all-electronic tolling.

From a bridge design and construction perspective, the Connector features numerous engineering challenges such as tight highway curvatures, extensive utilities, active railroad tracks, very high existing traffic flows, and limited space in which to build. The difficult site constraints required consideration of complex structural systems, erection methods, and marketplace-based bidding techniques to achieve a cost-effective and elegant project for the greater Tampa area. A combination of precast segmental concrete box girders and multiple erection methods provides the elegant solution envisioned by the Florida DOT District 7 and the many stakeholders who participated in the project development.

This presentation focuses on the design and construction aspects of the precast segmental concrete box girder structures which comprise more than 1 million square feet of deck area, primarily for the highly curved ramp structures. Multiple erection methods were required in order to build these ramps within the interchanges. The design philosophy of optimization for casting and erection simplicity will be presented, as will an overview of the nearly complete construction of the project. The I-4/Selmon Expressway Connector project gives rise to a new word—bridgelation!

The Truss Span of the S. Omaha, Missouri River Bridge

Kevin Eisenbeis • *Burns & McDonnell*

The Veterans Memorial Bridge, the official name of this Missouri River Crossing, is a 4,298 ft. structure with a centerpiece 625 ft. truss span. The US Coast Guard required a 590 ft. minimum clear navigation span at this river location. The truss is significant in size measuring 93 ft. between trusses and 90 ft. vertically at the tallest panel points. The roadway section has four traffic lanes, a 6 ft. raised median, 10 ft. outside shoulders and a 10 ft. pedestrian walkway and bike path. Total steel weight for the truss is 4,508 tons. With the emergence of the cable stayed and tied arch type bridges it is unusual to see the truss structure type selected for a situation like South Omaha. The presentation will describe the process from concept studies and structure type selection through erection of the truss. The discussion will include details and materials utilized to lower fabrication and erection costs. Some of the methods and means used by the contractor to erect the truss will also be presented.

3B ACCELERATED BRIDGE CONSTRUCTION

The Use of Accelerated Bridge Construction Techniques in the New Fraser Heights Bridge, Surrey, BC, Canada

David Harvey • *Associated Engineering*

The Fraser Heights Bridge is a twin 472 m and 436 m long viaduct crossing an environmental wetland in Surrey, BC, Canada. It traverses highly variable site soils comprising firm soils to deep, soft clays and peats at a site within a high seismic zone. The bridges were built as part of a design-build contract using site-specific accelerated construction techniques. Stringent environmental requirements limited the bridge footprint and prohibited access of heavy machinery to the wetland, leading to the development of a top-down construction scheme with an optimized pile size. Achieving the construction schedule using rapid bridge construction techniques was paramount, with each erection and construction operation being on the linear schedule-critical path. The typical 18 m span construction cycle included the installation of steel pipe piles and steel caps with a reinforced concrete connection, a continuous four-steel-girder system supported on laminated neoprene seismic-isolation bearings, and 250 mm full-depth precast panels. After each construction cycle (which averaged 7 days) the 200 tonne crane moved its work platform forward and advanced to the next span. The use of full-depth precast deck panels allowed for the delivery of construction material along the bridge prior to achieving composite action with the steel girders. Lack of preload time and limited site access added to the construction challenges and lead to creative solutions to meet the requirements.

The bridges were completed in late 2012, with the accelerated construction and environmental demands having been met, and achieving the stringent post-seismic return-to-service and settlement criteria. The design, construction methods, and key details will be described and illustrated with diagrams and photographs taken throughout construction.

Accelerating Bridge Construction: Recent Applications in California

Paul Chung, PE • *California Department of Transportation*

Jason J.Q. Fang, Ph.D., PE • *California Department of Transportation*

Topics: Prefabricated Bridge Elements and Systems for Accelerated Bridge Construction

The ever-increasing demands placed on the transportation network across the nation, coupled with the decaying infrastructure, have led to the omnipresent need to rapidly replace, widen, and build new infrastructure. Bridges form an integral element of the highway, linking sections of roadway pavement into a seamless network. They also require substantial design and construction efforts, lending to extended project development and completion time. Due to rapid economic and population growth, transportation planners are under increasing pressure to improve highway systems in accelerated time. To address this pressure, constructing a bridge using accelerated bridge construction (ABC) methods has been accepted as a viable alternative to the conventional construction.

Prefabricated bridge elements and systems, such as precast concrete girders and bent caps, lead the discussion of ways to accelerate on-site project completion. An added benefit to prefabricated components, when produced in an established manufacturing facility, is enhanced quality control due to repeatability in controlled environments not necessarily possible in field construction. While this innovative construction method has attracted the interest of bridge engineers, a majority of precast elements employed have been limited primarily to girders and few specific earth retaining wall types.

California is a region that experiences moderate to high seismic activities. Seismic loads have been the major design consideration for bridge engineers. To date the seismic performance of cast-in-place concrete integral connections has been widely accepted by bridge engineers. ABC structures using prefabricated bridge elements and system poses great challenges for bridge engineers to achieve the similar/better seismic performance to/than conventional cast-in-place construction. In 2006, the California Department of Transportation (Caltrans) has begun investigating feasibility of ABC and the seismic performance of the connections between the prefabricated elements. Over the last few years, Caltrans and other agencies have sponsored a series of research that tested newly-developed connection details, and the results showed promising seismic performance. This paper will present a summary of most recent progress in seismic ABC development. Several typical seismic ABC connections (precast girder connections, precast bent cap and column connections), will be discussed in detail. This includes seismic considerations, detail development, and seismic performance assessment. Also, several recent high-profile bridge projects in Southern California that employ the new seismic ABC details will be presented and discussed.

3C SEISMIC DESIGN

Design of the SR520 West Approach Bridge Using Seismic Isolation Bearings

Greg Knutson • *HDR Engineering Inc.*

The SR 520 Bridge Replacement and HOV Program is a $4.13 billion project that will enhance safety by replacing the aging floating bridge and keep the region moving with vital transit and roadway improvements between Seattle, Washington and the Eastside. Because of the operational importance of this route, the new bridges along the SR 520 corridor are classified as essential bridges and are being designed to meet project specific essential bridge design criteria. The West Approach Bridge is a 6,000 foot long, 42-span bridge that will connect the corridor's new floating bridge to the shoreline in Seattle. The design of the West Approach Bridge incorporates seismic isolation of the superstructure. The presentation will introduce the audience to this portion of the project and the reasons for selecting seismic isolation as the earthquake resisting system. It will also explain the fundamental concepts of seismic isolation design, discuss costs, procurement methods and other benefits of utilizing seismic isolation. Finally, the presentation will provide details on critical techniques used, assumptions made, and lessons learned while implementing seismic isolation bearing and performing a non-linear time history analysis of the bridge.

As-Built Seismic Analysis of the Golden Gate Bridge Main Suspension Spans

Ted Bush • *HDR Engineering*

This presentation provides an overview of the as-built seismic computer modeling of the landmark Golden Gate Suspension Bridge constructed in 1937. The bridge spans the Golden Gate Strait between San Francisco and Marin County in California. The Suspension Bridge is comprised of a 4,200 foot long main truss span and two 1,125 foot long side truss spans suspended from two approximately three foot diameter steel cables that are supported by two 746 foot tall steel towers. The goal of the retrofit (currently under design as Golden Gate Bridge Seismic Retrofit Phase IIIB Project) is to render the bridge sufficient to meet current seismic safety standards and allow it to maintain its function after the maximum credible earthquake (MCE). This presentation focuses on the engineering challenges that were encountered during the computer modeling and structural analysis phase of the project. It describes the nonlinear time history analysis techniques used to model the global behavior in ADINA and local superstructure behavior in SAP2000 for diagnostic and strategy evaluation of the existing Suspension Bridge spans and main towers. The seismic analysis and design are required to adhere to the project specific design criteria that include AASHTO LRFD and Caltrans specifications. The MCE is analyzed using three-directional and multi-support ground motion displacement time histories.

This presentation provides useful information regarding the seismic analysis for retrofitting a long span steel suspension bridge using displacement based nonlinear time history modeling.

Non-Linear Seismic Behavior of a Highly Horizontally Curved Bridge: A Case Study of Yerba Buena Island (YBI) WB On-Ramps, Bay Bridge, San Francisco, CA

Yong Deng • *Moffatt & Nichol*

Tom Lee, SE • *Moffatt & Nichol*

Gernot Komar, PE • *Moffatt & Nichol*

Omar Jaradat, Ph.D, PE • *Moffatt & Nichol*

Bridge structures experience non-linear behaviors under severe seismic events. Traditional elastic analysis methods are not suitable to predict non-linear behavior. It is a challenge for bridge engineers to perform nonlinear analysis and apply the results in the proper way. Caltrans Seismic Design Criteria (SDC) provides a good approach for non-linear structural analysis for ordinary standard bridges. However, for highly horizontally curved bridges, these methods are not proper and nonlinear time-history analysis can be used to simulate the non-linear structural behavior under severe earthquake movements. In order to demonstrate the non-linear seismic behavior for a highly horizontally curved bridge, a nonlinear time-history analysis will be presented using the Yerba Buena Island (YBI) West-Bound (WB) Ramps structures. These structures are part of the San Francisco-Oakland Bay Bridge (SFOBB) Project. The YBI On-Ramp and Off-Ramp are connected to YBI and the YBI WB Structure with hinges. This project is located within a 0.7g Site Specific Response zone for Safety Evaluation Earthquake (SEE). Understanding the overall seismic behavior is imperative for the SFOBB and similar projects. YBI WB On-ramp, with a radius of 127.3 feet (38.8 meters), is a good example of a highly horizontally curved bridge, and was selected as a case study. In order to understand structural nonlinear behavior, especially for highly horizontally curved bridges under severe earthquake events, the YBI WB On-ramp "stand-alone" bridge is analyzed using SAP 2000 developed by CSI. The Hilber-Hughes-Taylor ? direct integration method is used for the nonlinear time history analysis (NL-THA). Seismic modeling is also discussed in this paper. Six sets of acceleration time histories are used for the NL-THA. RM Bridge developed by TDV/Bentley is used to investigate and Open System for Earthquake Engineering Simulation (Open-SEEs) program developed by University of California-Berkeley is also used to check and compare to the NL-THA results. Caltrans SDC methods and Site Specific Response Spectra ARS are also used for liner analysis and are compared to the results of NL-THA and Open-SEEs analysis. Nonlinear push-over analysis is performed to determine the structural capacity and ductility under severe earthquake events. Finally, this presentation compares the different analysis methods and provided recommendations for analyzing highly horizontally-curved bridges.

3D BRIDGE REHABILITATION

Keene Road Railroad Bridge Conversion for Vehicular and Pedestrian Use

David McMullen • *KPFF Consulting Engineers*

The Keene Road Railroad Bridge was built in 1981 by Union Pacific to carry their tracks over Interstate182. The bridge is located in the Keene Road Corridor in the City of Richland, Washington. The bridge had not been under railroad or vehicular loading since its construction, and was being used to carry several utilities.

The bridge's original four spans total 412 feet in length, with an out-to-out width of 20 feet. The superstructure is a 9-foot deep continuous non-composite steel box with a 12-inch reinforced concrete deck. The span lengths are 81 feet 6 inches, 124 feet 6 inches, 124 feet 6 inches, and 81 feet 6 inches.

The intermediate piers are 13-foot by 6-foot tapered rectangular reinforced concrete pier walls founded on reinforced concrete spread footings. The abutments are seat type structures, each founded on a spread footing. Retaining walls are located in front of each abutment to provide grade separation between the embankments and the superstructure soffit.

The Keene Road project's goal was to convert the existing railroad bridge to accommodate two vehicular traffic lanes and a pathway carrying a walking trail across the Interstate. The existing deck was about 20 feet wide, covered by a waterproofing system and ballast. The proposed new deck would be about 40 feet wide, to accommodate the two 11-foot vehicular traffic lanes and the 12 foot pathway. A modified concrete (MC) overlay is proposed on the vehicular lane side to provide similar driving surface between the existing and the widened portion of the deck.

The recommended conversion alternative for the Keene Road Railroad Bridge was the Steel Overhang Frame. The superstructure work for this alternative included installing steel overhang frames attached to the existing box, adding additional cross-frames inside the existing steel box girder, and widening the deck from 20 feet to 41 feet 3 inches. The substructure work for this alternative included the abutment widening, removal and reconfiguration of existing retaining walls, and installing uplift anchors at the intermediate piers. The total construction cost for the bridge conversion was $3,801,727. This bridge reconfiguration produced a $3,000,000 savings over the cost of constructing a new bridge over the Interstate.

Rehabilitation of the Historic Oregon City Arch OR43: Williamette River Bridge

Jason Kelly • *OBEC Consulting Engineers*

The historic Oregon City Arch Bridge, designed by Conde B McCullough and built in 1922, has recently undergone a major rehabilitation. This bridge is a one of kind steel through arch with a gunite coating that received its first major rehabilitation in 90 years of service. This presentation will focus on two topics, the preconstruction condition evaluation to establish the scope of the rehabilitation work and some of the many unique structural details to accomplish the rehabilitation.

During the preconstruction phase, a number of bridge elements needed their condition evaluated including: the steel arch ribs, arch slabs, arch chambers, and floor system. The limited access, unique construction materials and the techniques used to construct the bridge made this task very challenging. We will discuss the complex safety issues, inspection tools used and findings of the condition evaluation.

Given the unique design and historical significance of this bridge the structural details for this bridge are complex and required careful consideration to accomplish the rehabilitation while preserving the historic integrity of the bridge. Some of the more interesting features we would like to discuss are: the removal and replacement of the gunite coating on the arches, the replacement of the railing system with a new and improved "stealth rail" that provides the necessary structural capacity while outwardly replicating the historic rail geometry, the reinforced structural plating of the arch ribs utilizing a new bolting technique, stringer repairs and hanger rod replacement.

4A BRIDGE DESIGN CASE STUDY

State of the Practice and Advances in Buried Bridges

Joel Hahm • *Big R Bridge*

Structural plate buried structures have been in use for over 80 years. These types of structures started out as a deeper corrugation profile option than traditional corrugated steel pipe (CSP) for use in hydraulic and minor crossings where CSP could not meet flow and size requirements and/or where bottomless structures were needed. Over the past 40 years there has been a significant increase in the use of structural plate as buried bridges in hydraulic crossing and grade separation applications where traditional bridges have traditionally been used. This has been made possible by advancements in design & analysis tools, manufacturing capabilities, materials, and development of deeper corrugation profiles to allow for longer spans, heavier loads, and higher cover. Benefits to the transportation industry have been in terms of lower costs compared to traditional bridges, increased security through redundant systems and the presence of a buffer against impact/explosions, improved aesthetics through the use of a wide variety of end treatments, environmental advantages, ABC advantages, and much lower maintenance and inspection costs compared to traditional bridges.

Design of structural plate buried bridges is covered in Sections 12.8 and 12.9 of the current AASHTO LRFD Bridge Design Specifications. Although structural plate structures have been in use for a long time and their use as buried bridges has been incorporated into the AASHTO LRFD design specifications, many engineers have the misconception that structural plate structures are more or less just large culverts and their applications are limited to minor drainage crossings. While there are some similarities with culverts, the level of analysis and design considerations involved with design of buried bridges is more detailed depending on the structural plate corrugation profile and structure application. In many cases, the design process can be more rigorous than design of traditional bridges and will also be dependent on site conditions and local construction practices. The goals of this presentation are to provide a brief introduction to buried bridges and the current state of the practice, outline design concepts, highlight key design inputs required from owners / engineers, and share the expanding list of applications. This will include an introduction to the AASHTO LRFD design requirements and include case studies. Among the specific topics to be discussed are design, materials, fabrication, load rating, environment, construction, and maintenance.

4B BRIDGE DECK CONSTRUCTION

ABCs of Crack-Less Bridge Decks, with Applications in Accelerated Bridge Construction

Sonny Fereira • *Caltrans*

For decades, the Holy Grail of crackless, enduring concrete bridge decks has eluded bridge engineers, researchers and field practitioners alike. Many have sought the methods for achieving a crack free bridge deck, but instead have had to settle for post-construction crack sealing countermeasures, until now. By combining today's technology of off-the-shelf shrinkage reducing admixtures, water reducing admixtures and fibers in the concrete mix, that long arduous quest for the perfect deck may be over. A method of "high performance curing" is found to produce a high quality early strength deck ready for traffic in just 3 days by reducing wet blanket cure time from the conventional 7 days by incorporating these admixtures. This presentation will chronicle some of the efforts of The California Department of Transportation over the past decade to produce "CRACK-Less" concrete bridge decks.

In the fall of 2011 Caltrans undertook its 3rd official Accelerated Bridge Construction (ABC) project under the FHWA Every Day Counts Initiative. EDC is designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment. The project replaced an aging scour critical 3-span Tee-Beam bridge over Craig Creek on route 99 near Red Bluff, California with a single span 108 foot long structure. In order to complete the bridge as planned in two stages and within the short construction window restrictions of the regulatory agencies, the chosen design used ABC methods with Prefabricated Bridge Elements and Systems (PBES) in lieu of conventional construction methods.

The bridge type selected used eleven side by side 3.5' deep x 4' wide precast box beam units with a 5" cast-in-place concrete deck, precast abutments and wingwalls, supported on twelve 2' diameter Cast-In-Steel-Shell concrete piles. The bridge designer chose a 5" thick 4000 psi site-cast composite concrete deck over other options, in part due to concerns of potential differential live load deflections between adjacent box beam sections affecting long term deck durability.

The General Contractor for the project, Blaisdell Construction Inc., Anderson, California, enthusiastically embraced the ABC concepts and furthered the project goals of reducing traffic delays, environmental risks, construction time and cost by submitting a Value Engineering Change Proposal (VECP) to the original plans. The approved VECP changed the planned one-way signalized traffic staging plans from occupying one-half of the bridge while the other side is removed and replaced to using a one-lane MABEY temporary bridge traffic diversion with continuous flagger control - bypassing the worksite entirely. Shoo-flying traffic around the footprint of the bridge gave the contractor the opportunity to complete the work in a more efficient single stage effort, reducing overhead costs, move-ins of subcontractors, construction time and related traffic impact costs. Having a larger lay-down/material storage area was safer and helped production. With the Value Engineering Change, 40% of the cost savings are shared with the State.

With the VECP pending, the challenge now was that if we could tear down an old bridge and rebuild a new one in its place in 3 weeks, why can't we figure a way to reduce the standard concrete cure time requirements from the "Standard" 7 day water cure (which would add 25% to the project duration!) and still end up with a high quality deck?

This question stimulated a 2011 Caltrans Construction-Evaluated Research study "Bridge Deck Concrete Improvements & Cure Strategies Proposed for Accelerated Bridge Construction," using the savings from the VECP to finance the construction components of the effort. This research study built upon previous experience and recent successes in reducing early age concrete deck cracking which are referred to in this article, and prototyped requirements for a high performance deck and cure specification suitable for ABC.

"Legacy" Standard Specifications require the C-I-P concrete deck to be cured using both a sprayed on "membrane-forming curing compound" and the water method. The wet-cure is to be applied following placement for at least 7 days before traffic loads are permitted. While technologies exist to accelerate rate of strength gain to achieve the required 4000 psi in 24 hours or less, the water cure time creates a "dead" spot in the construction schedule, contrary to the spirit of the ABC concept. Hence, it was desired to come up with a quicker cure time without jeopardizing deck concrete durability and life span. A quick literature search did not reveal any current research or methods relating to this need. This was not surprising, since anything less than a 7 day water cure is considered heresy in the bridge engineering profession! Utilizing a mix formula of shrinkage and water reducing admixtures with polyolefin macro fibers a "Crack-Less" concrete deck was achieved with a 3 day water cure period. Traffic was detoured on the rented MABEY bridge for just 29 days while the old bridge was removed and replaced, rivaling a duration of some of our "emergency" projects, Improving Mobility Across California!

How to Specify and Construct Durable Crack Free Bridge Decks: Washington State Experience

Mark Gaines • *Washington State Dept. of Transportation*

The aging and deficient bridge infrastructure of the country is facing a replacement crisis. As funding for replacement of deteriorated bridges is becoming scarcer, there is a renewed interest by many states in constructing bridges that can provide long service life with minimal maintenance costs. The early age concrete bridge deck cracking is one of the major contributory factors affecting durability and loss of service life in bridges. Cracks in bridge decks provide a direct root for water and salts to penetrate deep into the slab, initiating slab reinforcement corrosion, and the beginning process of rapid deck degradation due to the freeze-thaw cycles immediately after construction.

The State of Washington condition survey conducted indicates an average life expectancy of only 35 years (Thill 2006) for many concrete bridge decks. National surveys conducted by many researchers indicate similar trends in many other states (Aktan 2003).

The inappropriate use of high performance concrete (HPC) for deck construction has added to the confusion among practitioners and has exacerbated the problem. The advent of the HPC was to provide a concrete mix which improved durability and resulting in a more economical bridge structure due to its higher compressive strength. Inherent lower water/cementitious ratios and lack of bleed water in HPC mixes have contributed to bridge deck drying, plastic, and autogenous shrinkage cracking. This in turn accelerates salt penetration and leads to a considerable reduction in life expectancy of bridge decks. In fact, high cement content in such mixes is counter to the sustainability of materials and green movement.

The synopsis of the current available research results point to a number of deck shrinkage cracking causes and recommends remedies. The main factors identified are: concrete mix designs that have high paste content, restraint conditions, environmental variables, placement methods, curing practices, and use of deicing chemicals.

WSDOT has led the research in recent years to determine the root cause of this problem and has applied the research results in field experimentation to eradicate bridge deck cracking. Based on this research, WSDOT has developed a new performance-based specification that has been used on a number of projects and is showing promising results.

There is still some reluctance on the part of owners and contractors with respect to prediction of the environmental factors such as ambient temperature, peak hydration temperature of deck concrete, and material variability.

This presentation will bring into focus many causes of the early age concrete bridge deck cracking identified by the available research, influence of the environmental conditions, and best construction and maintenance practices. It will review the new WSDOT specifications which have contributed to construction of several bridge decks with significantly reduced or eliminated cracking. This presentation will also propose new tools which can aid the contractors and owners in preparation of deck placement. These tools are based on parametric studies and can predict deck and sub-strait temperature differentials using various cementitious contents at different curing temperatures.

Re-Surfacing the Orthotropic Steel Deck of the Freemont Bridge in Portland, OR

John Hinman • *CH2M HILL*

Spanning the Willamette River in Portland, Oregon, the Fremont Bridge opened on November 15, 1973 at a cost of about 80 million dollars. The main span of 1255 feet 4 inches made this structure the longest steel tied-arch bridge in the United States.

The upper deck of the two-deck bridge is an orthotropic steel deck and carries westbound traffic. The orthotropic steel deck length is 2,159 feet between expansion joints with a barrier-to-barrier width of 68 feet, and carries four 12-foot-lanes of traffic and two 10-foot wide shoulders.

The original wearing surface placed on the Fremont Bridge in 1973 consisted of 2-1/4 inches thick epoxy asphalt concrete (EAC) Type 3 placed in two courses. Epoxy asphalt concrete was selected because of its good performances as the surfacing material for both the San Mateo-Hayward and the San Diego-Coronado Bridges in California.

The wearing surfacing served well until 2002 when the heaviest traveled lane on a 5 percent downslope started to delaminate and shove. The EAC was replaced in this lane with ordinary asphalt that failed about every two years and had to be replaced each time it failed.

After a detailed study of available surfacing material, Oregon selected a new, reformulated, and more fatigue resistant Epoxy Asphalt Concrete as being the most cost-effective re-surfacing material. This wearing surface was installed in the summer of 2011.

This paper discusses the studies of wearing surface materials currently available in the U S and the selection process used to make the selection of Epoxy Asphalt Concrete as the wearing surface material for re-surfacing the orthotropic steel deck of the Fremont Bridge.

4C SEISMIC RETROFIT

Seismic Retrofit Program Priorities & Options for OR

Bruce Johnson • *Oregon DOT*

The Oregon coast is vulnerable to large seismic events from the Cascadia Subduction Zone (CSZ) which shares common seismic characteristics with those at Sumatra that generated large tsunamis in the Indian Ocean in December 2004, the recent Chile earthquake and the Japan Tohoku earthquake in 2011. Studies of tsunami deposits and evidences of coastal subsidence indicate that a large seismic event in CSZ occurs once every 300-500 years (Goldfinger et al. 2003). The most recent large seismic event in the CSZ occurred in 1700; therefore, there is a relatively high probability that a large seismic event will occur in the near future that could damage structures along the coastal area in the Pacific Northwest. However, Oregon has performed very little seismic retrofit due to the low recurrence interval of a major damaging earthquake. This paper will discuss the seismic risk in Oregon and a proposal for addressing the risk with strategic seismic retrofit projects. This paper describes Oregon Department of Transportation (ODOT) efforts to develop a bridge and landslide seismic retrofitting program and a method of prioritizing that program. This presentation will documents the processes used to evaluate risks and identify strategies to mitigate the seismic vulnerabilities of the highway system. The investigations and studies conducted to support this presentation resulted in a method to characterize the benefits to the Oregon economy by performing strategic retrofitting of bridge, landslides, and unstable slopes.

4D BRIDGE LOAD RATING

Load Rating for Two Steel Bridges

Jingjuan Li • *H. W. LOCHNER*

Two unique steel bridges were load rated by different methods. The first one is a highly curved steel plate girder bridge, which was rated by Load Factor Rating (LFR) method. The second bridge is a steel box girder with widening bracings, which was rated by Load and Resistance Factor Rating (LRFR) method. Due to the irregular geometry and structural components, standard load rating software was not applicable, special modeling techniques using SAP2000 software was used to determine the demand. The coupled behavior between axial and flexure, shear and flexure, and torsion and flexure were considered when determining the capacity. Iteration procedures were used to determine the load rating factors due to the coupled behavior.

The steel plate girder bridge is near the intersection of state route 167. The superstructure includes three curved steel plate girder with eight inch thick cast-in-place concrete deck. The bridge has 90 degree turn with 300 ft radius of horizontal curve. The bridge was designed in 1994. The LFR Method was used to rate this older bridge. Due to the highly curved horizontal layout, three dimensional models were developed to for live load analysis. The models use frame elements for each girder, lateral bracing and crossbeam. Shell elements were also used for the deck. Construction staging was considered to account for the non-composite or composite section. The items rated included the steel girders, lateral bracings, the supporting crossbeams at the intermediate piers and cap beams. The capacity of these components was determined according AASHTO standard specifications for Highway Bridges.

The steel box girder bridge converted an older railroad bridge into a vehicular traffic bridge. The new design load is HL-93. It was rated by the LRFR method since the design was completed in 2011. The conversion widened the bridge by adding outrigger bracings and edge beams at two sides of the existing single steel box. To account for the large torsion induced by the eccentric live load, additional internal bracing and deck tie members were added at the location of each pair of outrigger bracing. The lane configuration indicated large eccentricity of live load. The load path is not exactly same with typical steel-box Girder Bridge; hence three dimensional models were used to model the superstructure. The steel box is modeled with a single frame element. The bracing and box frame element are connected by rigid link elements to transfer the torsion. Considering the structural load sequence, constructions staging was incorporated into the model to model the non-composite section or composite section. The load rating items include:

- Existing steel box and splices: top and bottom flange stress, web shear, coupling of torsion and flexural, an iteration process has to be used for the coupling behavior.
- New edge beams: I beam top and bottom flange stress and web shear
- New outrigger bracings: combined axial (tension or compression) and flexural
- Internal cross frame members: axial tension or compression
- New deck tie: axial tension

5A DESIGN AND CONSTRUCTION OF ARCH BRIDGES

Design, Construction and Structural Health Monitoring of a Steel Arch Bridge

Aleksander Nelson • *HDR Engineering*

The presentation covers the design and construction of a single span steel thru-arch bridge over the Iowa River at Iowa Falls, Iowa replacing an existing concrete arch bridge listed on the National Register of Historic Bridges. The presentation will cover the type selection, design and construction of the new arch bridge. Some of the topics covered will be the historic and aesthetic considerations, site constraints, geometric and material choices for the arch, micropiles and the foundation of the arch, health monitoring systems and the special details and unique challenges of the construction of the arch bridge.

Design and Construction of the Bronco Arches Replacement Bridge

Gregg Reese • *Summit Engineering Group, Inc.*

The Bronco Arches were a landmark series of steel arches supporting IH25 over the Platte River adjacent to Mile High Stadium in Denver, CO. The arches, built in various stages over the previous 60 years, were seriously deteriorated and have been replaced by a new, innovative, precast concrete bridge. The new bridge was Value Engineered to maximize the use of precast concrete and to construct the abutments and retaining walls under the existing bridge prior to demolition of the existing bridge to accelerate the time of construction while minimizing disruption to existing traffic.

The superstructure is a three span bridge built in four phases. The superstructure consists of a fully precast deck slab supported on eight lines of continuous, spliced, precast concrete U girders. The bridge deck consists of full depth, deck panels that are grouted to the supporting girders and post tensioned to result in a fully compressed concrete superstructure. The spliced, precast concrete U girder superstructure uses a combination of pre-stressing and post-tensioning and an innovative erection sequence that greatly reduced the total time of construction.

The substructure consists of integral abutments on a 60 degree skew that parallels the banks of the Platte River and accommodates bike trails and a trolley line and 16 precast piers. Each pier is fully precast with two arch shaped shafts. The piers are erected with cranes and are temporarily supported on shoring until it is connected to a single drilled shaft foundation with a cast in place base element.

The completed bridge is an elegant rigid frame, precast concrete structure with enough flexibility to accommodate longitudinal movements without bearings. The bridge aesthetics simulate the look of the arches with a graceful structure while creating an appealing, open recreational space below. The project creates an elegant, signature structure for Denver along the Platte River recreational corridor while expanding and upgrading the Interstate 25.

The paper will describe the design and construction engineering of this innovative bridge project which will be completed in early 2013.

5B BRIDGE PRESERVATION

Developing an Effective Bridge Preservation Program

Chris Keegan • *WSDOT*

It takes bridge professionals from multiple disciplines, design, inspection, programming, and maintenance, to develop a good bridge preservation program. It starts with a design that incorporates easy to maintain details and materials with the long term maintenance and preservation needs of the bridge in mind. During the construction phase the inspectors must ensure that the bridge is constructed as designed, that all tolerances are met, that the materials are as specified, and that the work is complete, including the clean up at the end. Prior to closing out the construction, the bridge needs to be bought off by those who will be charged with its long term maintenance.

To keep the good bridge in good condition will require timely inspections as well as preservation and maintenance activities designed for the bridge, that take into consideration the annual daily traffic, the materials it is constructed of, the type of joints, the deck type, and the chemicals the bridge is exposed to.

As our infrastructure ages our bridges deteriorate and the repair needs have increased. At the same time our revenue has been shrinking. The funds are not available to replace the older bridges in our inventory. We had to find a way to extend the life of these assets and to move from strictly corrective maintenance to a more proactive preventive maintenance program.

Within the Olympic Region of the Washington DOT we have been doing a number of pilot programs to determine the cost and effectiveness of certain bridge preventive maintenance actions. In the talk I will discuss what these preservation activities are, how we implemented them, what it cost, and what effect the preservation actions have had on the bridge repair program.

How Do You Inspect Something You Can't See? Oregon's Experience in a Pilot Program to Test PT Ducts

Marie Kennedy • *Oregon Department of Transportation*

Post tensioned bridges have been used in our infrastructure for more than 40 years now. While they provide an alternative to steel for long span bridges, much of the strength the bridge receives in the way of post tensioned tendons has been covered in grout and concrete. How do we know the conditions of such a vital part of the bridge when it is covered in concrete? With the help of a consultant (Wiss, Janney, Elstner Associates) Oregon opened up PT ducts in two of its bridges. The process is defined in a method of destructive testing. The results are interesting as the corrosion uncovered was not expected based on a visual survey. The pros and cons of destructive testing will be investigated. The choices that Oregon now has for these two bridges and the rest of the PT ducts in the state will also be discussed.

5C SPECIAL DESIGN AND CONSTRUCTION

Design of the Truckee River Bridge

William Rodriguez • *TYLIN International*

The Veterans Memorial bridge is part of the SouthEast Connector project in Reno, NV. The structure is 1,413 ft long and includes the main bridge over the river and the viaduct, the structure is located in a highly seismic and environmentally sensitive area.

Five bridge alternatives were considered: precast P/S girders, c.i.p. post-tensioned box girders, prismatic steel plate girders, haunch steel plate girders and a combination of prismatic steel girders on the viaduct and a steel arch across the river. The P/S girder bridge was eliminated because of limitations on span lengths and the P/T box girder bridge was not feasible because falsework was not permitted in the environmentally sensitive area. It was determined that the most economical and aesthetically pleasing structure would be a combination of prismatic steel plate girders for the viaduct and haunch plate girders across the river.

The Veterans Memorial bridge is comprised of two bridges, consisting of three frames each. The bridges are on a horizontal curve, the SB bridge has a constant deck width and the NB bridge deck varies in width, the maximum depth of the superstructure was limited by the roadway profile and the 117 year flood event.

The complex horizontal roadway geometry on the NB bridge presented design challenges including modeling and detailing of the tapered curved girders and the integral steel diaphragms.

Design of Keechelus Lake Avalanche Bridges

Cory Caywood • *Jacobs Engineering*

Kevin Dusenberry, PE, SE • *Jacobs Engineering*

The Keechelus Lake Avalanche Bridges are a part of the I-90 Hyak Cost Reduction Incentive Proposal (CRIP), which is a part of the "Snowshed to Keechelus Dam Phase 1C Replace Snowshed and Add Lanes" project. The project is located on I-90 just east of Snoqualmie Pass, about 55 miles east of Seattle, Washington.

Overall, the project widens I-90 from 2 to 3 lanes in each direction and widens the shoulders to improve safety and capacity. The original project included replacing the existing 500' long snowshed for the eastbound lanes with a new 1,100' long snowshed for the eastbound and westbound lanes to reduce disruptions to traffic caused by avalanches. The CRIP proposed by the contractor instead replaces the existing snowshed with two 1,206' long bridges (1 for eastbound and 1 for westbound). The advantages of the CRIP include reduced construction risk to WSDOT, as well as reduced maintenance cost that would be required for the snowshed.

The bridges were piers were designed for loading associated with avalanche impacts on piers and seismic induced landslides.

The presentation will give an overview of the project and focus on design elements related to the bridges, including:

- Design for avalanches
- Design for seismic induced landslides
- Brief update on any construction activities for summer 2013

5D LIGHT RAIL BRIDGE PROJECTS

Design of the East Link Aerial Guideway Structures in Bellevue, WA

Jerry Dorn • *HNTB Corporation*

H-J-H Joint Venture (Joint venture members consist of HNTB Corporation, Jacobs Engineering Inc. and Hatch Mott MacDonald)

The East Link project includes approximately 7 miles of double-track Light Rail Transit (LRT) line and stations between the I-90 East Channel Bridge and the Overlake Transit Center Station. It includes eight stations, , approximately 9,400 feet of aerial guideway, 200 feet of trestle structure, long span crossings over I-90 and I-405, 11,000 feet of retained cuts, a 2300 foot sequential excavation method tunnel, 2100 feet of retained fill, and 8900 feet of at-grade track. The project will be advertised in five major packages, E320, E330, E335, E340 and E360. The aerial guideway deck is dual track structure 28' wide. The dual track structure splits into two single track structures at the approaches to the center platform aerial stations. The typical structure type is simple span prestressed concrete tubs, with continuous prestressed tubs at the aerial stations and cast in place segmental boxes for the long span structures at I-90 and I-405. There is a three span continuous curved tub structure at the crossing over NE 116th to provide for future NE 6th extension. The piers are typically single columns constructed on drilled shafts.

The design criteria includes a dual level seismic design event. The Operating Design Earthquake (ODE) has a return period of 150 years and the Maximum Design Earthquake (MDE) has a return period of 2500 years. The structure is designed to respond to the ODE event without significant structural damage so it can return to service while repairs are made during normal operating hours. The MDE event design is to maintain life safety and prevent collapse of the structure.

The modeling was accomplished using CSI Bridge and rail-structure interaction models that modeled individual rails so rail stresses, loads and displacements could be determined for the continuous rails option and for the rail break option. Individual rails are linked to the superstructure so non-linear rail slip at the rail connection clips are included in the model.

Superstructure design of the concrete tubs was accomplished using WSDOT PGSuper program and CSI Bridge program.

PHX Sky Train: Taking Trains Under Planes

David Burrows • *Gannett Fleming, Inc.*

As far back as the late 1980's, after Terminal 4 was constructed at Phoenix Sky Harbor International Airport, the City of Phoenix Aviation Department was studying how to integrate a transit system to connect key facilities at the airport. Their research showed that a secondary transportation system was imperative for the relief of roadway and curbside congestion, and increasing passenger safety.

Gannett Fleming (GF) was selected by the City of Phoenix Aviation Department as the lead designer in the development of the facilities for the PHX Sky Train™. A collaborative planning effort between GF and the Aviation Department led to a predominantly elevated train alignment that offers the most economical facilities and the best level of service for station connections to airport facilities.

The culmination of years of planning and design, the Sky Train Stage 1, the first half of the 5 mile long automated transit system, opened to the public on April 8, 2013. Stage 1A, which is now under construction, builds a new station at Terminal 3, approximately ¾ mile of guideway and a walkway to connect the new station to Terminal 2. One of the biggest challenges for Stage 1A was crossing beneath Taxiways Sierra ("S") and Tango ("T").

After careful consideration and discussion with stakeholders, the concept of crossing the Taxiways evolved into adding a new span on the south side of the existing Taxiway bridges that cross over Sky Harbor Blvd., so that the train system could be built at approximately the same elevation as the roadway. Concerns regarding the number of identified and potentially unidentified utilities in the area, clearance requirements for the train system, Taxiway shutdown schedule, and cost were ever-present during design development.

GF engineers worked with the CM-at-risk contractor, McCarthy Kiewit Joint Venture to address the concerns and come up with innovative solutions. To mitigate cost and schedule constraints, the final design eliminates a separate foundation for the north abutment and instead is founded on the existing Taxiway's spread footing. To resolve clearance requirements, the new span is haunched at the abutments, leaving a reduced superstructure depth throughout the majority of the span with sufficient room for the train's clearance envelope. To address utility concerns, the south abutment minimized excavation requirements by using a unique combination of cast-in-place concrete cap supported by drilled shafts with a shotcrete wall facing, restrained at the top by a cast-in-place anchor slab.

Construction of the new span of Taxiway S began in late May 2012 and progressed quickly, allowing a re-opening on November 14, 2012, five days ahead of schedule. Construction of Taxiway T's new span started at the beginning of January, 2013 and was re-opened with its new span on June 11, 2013, three weeks ahead of schedule. PHX Sky Train's Stage 1A is scheduled to be open to the public in early 2015.

I-90 Track Bridge: The Reality of Taking Light Rail Vehicles on to the Homer M. Hadley Floating Bridge

Thomas Cooper • *Parsons Brinckerhoff*

The Central Puget Sound Region's transit agency, Sound Transit (ST), is planning to install light rail transit (LRT) tracks on the I-90 Homer Hadley floating bridge as part of the 14-mile long East Link project. Placement of light rail across the floating bridge presents unique challenges because project criteria require that dynamic, multidimensional movement of the bridge deck at the existing expansion joints, due to changing lake elevations, vehicle traffic loading, wind, waves and, for extreme conditions, be addressed in the design.

In February 2011, Sound Transit contracted with a team led by Parsons Brinckerhoff Inc. to identify, develop, analyze, and evaluate conceptual designs of a "track bridge system" that would meet its light rail service performance objectives, and then fabricate, test the prototype design, and install the track bridge. The conceptual design phase concluded with the selection of an innovative solution, the so-called Curved Element Supported Rail (CESuRa) device.

The CESuRa track bridge prototype design has since undergone rigorous engineering and computer modeling studies of the track and structure behavior as well as modeling of the LRV performance using the industry standard NUCARS computer program to prove out the concept. The prototype design is now undergoing a physical testing program that includes recently completed component tests at the University of Washington and full-scale tests at the Transportation Technology Center in Pueblo, Colorado, for which the test track and track bridges are currently under construction.. The full scale testing will take place from August to October 2013.

This paper will address the approach to developing the concept, analytical and engineering studies to determine the validity of the design and the physical testing program for components and prototype. It will also discuss findings of the component tests and provide an update on the full-scale test program.

6A DESIGN AND CONSTRUCTION OF STEEL BRIDGES

Fracture and Fatigue Properties of Seriously Damaged Steel, Bridge Structural Members Repaired through Heat-Straightening

Kaiyuan Liu • *Parsons Brinckerhoff*

The heat-straightening method has been employed for repairing damaged steel bridge structural members for many years. While many research have proven that damaged steel with the degree of damage (or strain ratio, a term to define how serious the damage is) of up to 100 can be safely repaired through heat-straightening without significantly degrading its mechanical properties, this paper presents the experimental studies for heat-straightened steel plates with much larger degree of damage (strain ratios up to 200). Furthermore, besides the more traditional mechanical properties such as tensile strength and CVN toughness, the J-integral resistance curves (or J-R curves) and fatigue properties are also discussed.

This paper demonstrates that the ductility and CVN toughness of heat-straightened steel plates with extremely serious damage are significantly reduced. The J-integral characterized fracture toughness is getting larger while the crack propagates much more rapidly for more seriously damaged steel plates. The data collected during fatigue pre-cracking procedure are also analyzed and the corresponding fatigue resistances are found reduced with increasing strain ratios. Finally, it is concluded that heat-straightening may not be recommended to repair a seriously damaged steel bridge member, especially for fracture critical bridges.

Design & Construction of the Shenandoah River Bridge Steel Delta Frame

Jason Fuller • *HDR Engineering, Inc.*

The new alignment of West Virginia, Route 9 is in the eastern panhandle of the state, with a portion of the roadway to span over the scenic valley that holds the Shenandoah River. As a Design-Build project, HDR Engineering, Inc. and Trumbull Corporation teamed for the design and construction of this bridge. After an extensive investigation during pre-bid, the Design-Build Team determined that within the project geometric and environmental constraints, and for the prevailing material and construction costs at that time, a steel delta frame bridge would be the most efficient solution.

The structure included two 123′ steel plate girder approach spans, and the main structural unit which spans a horizontal distance of 1400′ over the 200′ deep valley. The steel superstructure consists of a 5-girder, 4-substringer system that is supported by five lines of delta legs, one for each girder. One girder line consists of two sets of delta frame legs, each set containing two legs. Each individual leg covers a vertical distance of 150′ and a horizontal distance of 150′, creating a girder span of 300′ between the delta legs. This creates girder spans of 250′-300′-300′-300′-250′ between supporting legs and spans of 400′-600′-400′ between end supports and piers.

Rising almost 200′ above the valley below, the Shenandoah River Bridge is one of the largest steel delta frame structures in the country. This presentation illustrates the detailed analysis and design of this unique and complex structure, highlighting the design challenges and the engineering that such a project entails. Also to be presented will be the detailed construction and erection plans that were developed that had to account for the erection heights, uniqueness of the delta leg erection when the deltas were incomplete, tall temporary works, small site footprint, fluctuating river levels, and other unique site conditions. A finite element analysis of the erection procedure was developed so each step could be examined individually and so that the temporary works and permanent steel framing could be accounted for as a system to provide stability to the structure until completed. Additionally, challenges that arose from estimating the erection at pre-bid for the Design-Build to solving them and implementing the plan during final design and construction will be discussed.

6B BRIDGE MANAGEMENT

Bridge Paving Design, Construction, and Management

Bruce Thill • *Washington State Department of Transportation*

Bridge paving needs are often over looked in design, construction, and management because it is such a small portion of the roadway paving. Even though bridge paving can be small cost of most paving contracts, it usually has different design criteria and construction that demand exceptions to roadway paving. If mismanaged or ignored, the small cost can become a very large cost. The 2012 National Bridge Inventory data indicates 40.2% of the traffic bridges have asphalt paving, which is 808 million square feet or 24.7% of the total bridge area in the United States. Even though bridge paving can range from a low cost of $1.00/SF, it can easily grow to $10.00/SF or more when managed improperly. This topic presents the common issues that should be addressed in design and construction to properly manage bridge paving.

Improving Load Ratings & Bridge Management Decisions: Field Testing of the Jackson St. Bridge

Brice Carpenter • *Bridge Diagnostics Inc.*

Bridge owners face numerous challenges managing their bridge inventory with limited resources while dealing with an ever increasing number of deficiently rated bridges. This paper uses the on-going Jackson Street Corridor Rehabilitation in Seattle, WA to illustrate the benefits and effectiveness of field testing as a bridge management tool. During this project, the Seattle Department of Transportation (SDOT) utilized diagnostic load testing, concrete core testing, and the subsequent accurate rating results to better quantify the structure's live-load capacity. Since the structure was found to perform better than originally assumed, the planned scope of rehabilitation work was reduced and significant resources were saved.

In 2006, the City of Seattle resurrected their streetcar operations and is currently building a second line along the Jackson Street Corridor. During the planning phase of this streetcar line, an initial structural evaluation was conducted due to concerns with the existing bridge system's capacity along this corridor. It was determined from this evaluation that the bridge's load rating was well below 1.0 (RF = 0.42) for the proposed streetcar loads. Consequently, a substantial amount of beam strengthening was recommended in order to bring the bridge rating above 1.0 for the streetcar loads.

It was understood that these standard ratings relied on assumptions related to unknown construction details, historic maintenance work, material properties, and existing levels of deterioration. In order to verify and quantify the effects of these parameters, SDOT elected to utilize a field testing program that involved diagnostic load tests, concrete core tests, and a field-verified load rating procedure. The testing goals were to obtain a more realistic understanding of the structure's load behavior and determine the in-situ concrete compressive strength. SDOT's past experience using live-load testing and concrete core testing of these types of structures has resulted in improved load ratings.

The instrumentation and load testing was performed in a single day. A wireless structural testing system with 62 sensors measured strains, rotations, and displacements along the structure under controlled load scenarios. Once the load testing was complete, a finite-element model of the structure was created and subsequently calibrated until analytical responses accurately simulated the measured values. Realistic representations of the actual load paths observed during testing provided a more accurate load distribution throughout the structure and an improved rating accuracy for the numerous possible load combinations of the streetcar and other traffic loads.

The final result of the field operations was that the superstructure's load ratings were all found to be acceptable. The primary factors in the increased load capacity were the higher concrete compressive strength obtained from core tests and a significant reduction of live-load applied to individual beams due to the structure performing like a continuous two-way floor system. Reinforcement details at isolated locations did not meet current code specifications so some retrofits were still required. However it was found that the extent of the initially recommended strengthening was unnecessary. A reduced scope for the rehabilitation plan is currently being finalized.

6D BRIDGE AESTHETICS

Genesee Avenue Pedestrian Overcrossing: A Concrete Bridge with High Degree of Curvature

Paul Morel • *Kleinfelder-Simon Wong Engineering*

Nathan Johnson, Ph.D., P.E. • *Kleinfelder/Simon Wong Engineering*

The Genesee Avenue Pedestrian Overcrossing (POC) in San Diego, California will provide a direct connection across Genesee Avenue for a new bicycle and pedestrian path that will run parallel to I-5 on the west side. The two-span, 260-foot-long, 18-foot-wide, cast-in-place reinforced concrete box girder bridge was designed for an extreme horizontal curve (115-foot radius). The bridge will be supported on a single-column bent and diaphragm-type abutments, which serve as a creative solution to handle the torsional demands imparted by the superstructure. The unusual curvature of the bridge required a high level of analysis for the superstructure that included development of a grillage model and a 3-D finite element model.

The grillage model, used to design the bridge, was developed in accordance with the guidelines included in the 2008 NCHRP Report 620 "Development of Design Specifications and Commentary for Horizontally Curved Concrete Box-Girder Bridges" (Nutt, Redfield and Valentine). The model consisted of longitudinal beams located along each girder line and transverse beams to model the bridge deck, soffit, and all diaphragms along the span.

The 3-D finite element model was developed to confirm appropriateness of the grillage methodology, as well as to perform a full independent check of the design. Thin shell elements were used to model the deck, girders and soffit. The shell finite element method implicitly captures issues related to high degree of curvature including shear-flexure-torsion interaction, shear lag, and twist deformations due to distortion of the cells. To supplement the independent check of this non-standard structure, the designers elected to seek out peer review of the design methodology.

Aesthetics were a major consideration for this bridge. Close coordination with the City of San Diego, Caltrans and the bike coalition was required. The horizontal curve of the bridge was ultimately chosen not only for the functional purpose of providing an uninterrupted pathway across Genesee Avenue for the benefit of the bicycle users, but also to provide a uniquely shaped signature structure for the coastal corridor. Integral colored concrete, column flare, pilasters behind each abutment, form liners, weathering steel railing and lighting integrated into the concrete barrier faces were all added to the final design of the project to complete the desired aesthetic theme.

The project was greatly accelerated in order to take advantage of additional state funding sources that became available as the planning phases of the project progressed. This required completion of a full PS&E package including final approval by Caltrans Office of Specially Funded Projects in a matter of four months, which included nearly one month of review time for Caltrans. The design team was successful in meeting this challenging deadline.

Bridge Architecture Current Trends: A West Coast Bridge Architect's Perspective

Paul Kinderman • *WSDOT*

West Coast bridge architects Michael Fitzepatrick and Paul Kinderman will discuss aesthetics. TyLin's Fitzepatrick and WSDOT's Kinderman are among a handful of bridge architects in the United States.

Fitzepatrick will discuss projects worldwide. He will present the architectural

development of the I 395 replacement structure in downtown Miami. The I 395 corridor is the access to South Beach, at the center the Performance Art District, a block away the AAA where the Miami Heat play, along the axis of high end condos and under the flight path alignment into MIA. When the existing bridge was built it divided the section of the city named Overtown. The project not only maintains full traffic movements, aims to restore the urban fabric under the highway and has a signature structure over Biscayne Boulevard. The presentation will highlight the CSC approach and concept development.

WSDOT architect and engineer Kinderman will discuss case studies of Washington State's major bridge replacements. The Columbia River Crossing and the Evergreen Point Floating bridge replacements require billions of dollars to construct. Paul will discuss the FHWA Context Sensitive Design method among other topics.

At the conclusion, both architects will discuss aesthetics design philosophies. Conversation will ranging from Louise Sullivan's mid 19th century 'form follows function' theory to David Billington's 20th century observation that 'function follows form'.

Aesthetic Bridge Rails and Barriers in California

Shannon Post • *California Department of Transportation*

This presentation will share a palette of aesthetic bridge rails developed and implemented by the California Department of Transportation over the last decade.

This presentation will discuss how owners can successfully address design issues for bridge rails, including structural and safety considerations, and provide projects that are compatible with the context of the surrounding environment.

Bridge railings often serve both safety and aesthetic functions in bridge projects. The railings are designed to safely redirect errant vehicles and to retain pedestrians and bicyclists. The railings can also be designed to integrate the transportation project with the community and the local environment.

There are four classes of bridge railings, each intended to perform a different function: vehicular, combination vehicular and pedestrian, pedestrian and bicycle. After determining the function of the bridge railing, the designer must consider a series of parameters in the preliminary design: vehicular design speed, railing height, structural materials (generally concrete or steel), constructability, maintenance and initial and life-cycle costs.

The designer must ensure that the bridge railing meets the structural requirements in the AASHTO LRFD Bridge Design Specifications, Section 13. Bridge railings must meet crash test requirements. Approved bridge railings in California comply with NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features. New bridge railings under development must comply with the requirements in MASH, the Manual for Assessing Safety Hardware.

When developing "see-through" or aesthetic bridge rails, the designer must consider the requirements of the local environment or community. This is particularly important for structures in the California coastal zone, where aesthetic bridge rails help minimize impairment of views both of and from the ocean and other scenic areas. The designer can further enhance the visual appeal of the bridge rail by applying color, texture and other architectural treatments, as long as the modifications do not impact the crashworthiness.

The most commonly used "see-through" steel rail in California is the CA ST-10. It has been constructed at numerous locations around the state, notably at the Ten Mile River Bridge and the Presidio Parkway in San Francisco. This rail is easily modified for both function and form.

The most commonly used "see-through" concrete barrier in California is the Concrete Barrier Type 80. It has been constructed at numerous locations around the state, notably at the Bear River Bridge and the newly completed Devil's Slide. It is also easily modified for function and form.

7A SPECIAL BRIDGE DESIGN AND CONSTRUCTION

Landmark in the Works: Novel Use of Post-Tensioning in Highly Curved Bridges

Huanzi Wang • *AECOM*

The Mountlake Triangle Project (MTP) Bridge is a highly-curved 400-foot long cast-in-place (CIP) post- tensioned pedestrian bridge spanning over Mountlake Boulevard between the underground Sound Transit light rail station at the University of Washington (UW) and the UW campus in Seattle, Washington. The horizontal geometry resembles a highly curved "X" in plan view, including a forked superstructure at each end of the bridge. The vertical design constraints required the bridge to drain and match predetermined elevations for three sets of stairs, two elevators, temporary and permanent vertical clearances for traffic, and permanent clearances for pedestrians and bicycles. Steel is usually the option for highly curved bridges however the client, Sound Transit, requested the use of concrete for its ease of maintenance. Typically post-tensioning (PT) is not used in highly curved bridges due to the difficulties associated with handling the large out-of-plane forces induced. However, for this bridge, post tensioning was chosen because it allowed a shallow section that met the vertical clearance and bridge profile requirements. The 92-foot minimum horizontal radius of curvature required special PT analysis, detailing, and construction. The post-tensioning of this bridge resulted in plan distortion due to the bending about the vertical axis. This undesirable plan distortion was minimized by designing the deck as a stiff element. Different PT tendon forces were used for each of the four bridge webs, roughly in proportion to the span of each web. In-span hinges were added to the bridge to divide the bridge into three more regular bridge segments, which improved the overall static and seismic bridge behavior and simplified the analysis and design. Uneven span arrangement required the use of special design techniques to compensate live load uplift reactions at pier and in-span hinge bearings. Analysis included the use of complex 3D finite element structural modeling techniques to capture the static and dynamic behavior of this uniquely shaped bridge. The bridge is supported by drilled shafts, spread footings and the light rail station itself. A special seismic design criterion was developed to satisfy bridge (displacement based) and building (force based) code philosophies for the spans supported by the UW light rail station. Construction of the bridge, which is ongoing with the structural work scheduled to finish in August 2013, requires the use of special formwork. We anticipate that the remarkable and elegant shape of the bridge will make it a landmark in both the University of Washington and the City of Seattle.

Design of the SR 99 Bored Tunnel and Approach Structures in Seattle, WA

Jerry Dorn • *HNTB Corporation*

Upon completion in 2015, the SR 99 Tunnel in Seattle will be the world's largest bored tunnel in diameter. In December 2010, WSDOT awarded the SR 99 bored tunnel design-build project to Seattle Tunnel Partners (STP) based on best technical solutions and cost. STP is a joint venture of Dragados USA and Tutor Perini Corp. The design team includes HNTB Corporation, Intecsa of Spain, Hart Crowser, Inc., and Earth Mechanics, Inc.

The tunnel has an outer diameter of 56 feet and will be constructed with a 57.4-foot diameter tunnel boring machine (TBM). The SR 99 Tunnel Project consists primarily of a 1500-foot cut-and-cover structure at the south end, a 9300-foot long bored tunnel, tunnel interior structures, a 460-foot cut-and-cover structure at the north end, and two operations buildings. The south approach structures have reinforced 5' diameter secant piles supporting the cast in place bottom slab, roadway slab and lid slab. The secant piles provide vertical and lateral support for the approach structures. The bored tunnel consists of 2' thick precast liner segments with a cast in place interior roadway structure. The north approach structures are made up of soldier pile temporary retaining walls with cast in place bottom slab and roadway slab with a prestressed girder lid structure.

Under a design-build contract, the designer addressed technical requirements for anticipated service load conditions and dual-level seismic design criteria. This presentation will present design steps and issues encountered in the final design of the cut and cover approaches, launch pit and receiving pit, precast tunnel liner and tunnel interior structures.

The design was accomplished using soil-structure interaction models that required close collaboration between geotechnical and structural engineers. The geotechnical engineers created a two-dimensional continuum model to quantify the soil loads and the hydrostatic loads. The stiffness of the surrounding soil was obtained by performing pushover analysis. The structural engineers created two-dimensional and three-dimensional beam-spring models. The soil-structure interaction was modeled by using springs with stiffness obtained in the geotechnical model. The structural engineers then calculated the effects of the soil loads, hydrostatic loads, and ground deformations, and applied load combinations as prescribed. For the seismic design, a time history analysis was conducted using the beam-spring model rather than the continuum model, in order to make the computational time manageable in a design environment. This approach also allowed the structural engineers to apply different load factors and various load combinations in the structural model.

Accelerated Design/Construction Using Prefabricated Bridge Components

Merv Eriksson, P. E. • *DJ & A, P. C.*

Late Federal budgets make fitting designs into obligation periods and bridge contracting into short construction seasons progressively more difficult for Federal Land Management agencies.

In September of 2009 the US Forest Service received stimulus funding to replace eight severely deteriorated, or missing, remote single lane bridges. Funding guidelines required the bridges be under contract by early 2010 and be completed in 2010. The Forest Service and Western Federal Lands, FHWA contracted with DJ & A, P.C. of Missoula, M,T to design the eight bridges and provide construction assistance.

We contracted bridge construction in two stages: 1) a fabrication/delivery contract furnished modular bridges superstructures, including TL 2 bridge rail systems and 2) a construction/installation contract removed the remains of the existing bridges, constructed permanent foundations, and installed the new bridge superstructures and guardrails.

Two phase contracting allowed supply of f the bridge superstructures, while designs were being completed for the bridge abutments. The contract to design was delivered to DJ & A on September28th. By the end of the calendar year the eight bridges had been sized, the superstructure type and bridge rail selected, and contract documents for the supply contract had been completed. The supply contract was advertised and the selected bid was awarded on February 10th for delivery by April 25th.

While the supply contract was underway, DJ & A completed design of permanent foundations for the eight bridges, and contract drawings and documents for construction and installation. Foundation conditions varied significantly from site to site. Of the 16 abutments for the eight bridges, six were on bedrock, five were on large boulder, and five were on relatively loose stream deposited gravels.

Cast-in-place footings were constructed at the five abutments where bedrock was exposed.

Micro pile abutments were drilled at the six abutments where larger boulders were present.

Mechanically stabilized earth walls were constructed at the five loose gravel abutments. The Hilfiker wire baskets were faced with treated timber to prevent snagging by woody debris.

The funding language strongly encouraged the Forest service to "spread the word" among small local contractors. We split the construction into three installation contracts. These three contracts were advertised by mid-February and awarded in early April.

Delivery of the prefabricated bridge superstructures was scheduled for April 15th with construction of the bridge foundations scheduled to begin about the same time. Deliveries of the steel superstructures were coordinated with the installation contractors and made directly to the bridge sites. All eight bridges were completed by mid-September of 2010, less than one year after beginning design.

Construction costs for these eight remote bridges totaled about $2.5 million, or $250 per square foot. Design cost, including site surveys and geotechnical investigation, totaled approximately $240,000.

7B BRIDGE PRESERVATION

Summary of ***Critical Findings*** Reviews for the National Bridge Inspection Program

Brian Leshko • *HDR Engineering, Inc.*

The Federal Highway Administration (FHWA) reviewed the current state of highway bridge inspection practice for identifying and following up on critical findings through a contract with HDR Engineering (HDR). Twelve States were visited during June-August, 2011 by HDR staff as part of an independent review team to assess processes and procedures for reporting and tracking critical bridge inspection findings (critical findings). The team visited State offices and bridge sites to review bridge inspection information and gain a better understanding of how this important area of the bridge safety program is administered. The team interviewed FHWA staff, State bridge inspectors and State inspection program managers, and investigated aspects of bridge inspection and other events that can lead to critical findings. This included fracture critical findings, scour critical deficiencies and plans of action, load rating calculations, critical findings on any primary bridge component, and other safety deficiencies. A summary report was developed to highlight best practices and areas for improvement, and provides a basis for improved processes for identifying, monitoring and correcting critical deficiencies. The areas of good practice and areas of improvement will improve processes used by bridge owners to take timely corrective measures to avoid bridge closures that may occur due to deficiencies, and to prevent bridge failures. Sharing common areas of good practice and common areas of improvement with other bridge owners supports the overall objective to improve the critical findings process and provides tools for the FHWA to better manage the bridge inspection program. There are many examples of good processes in place that can be used by State and local agencies who are interested in establishing or improving the way they address critical findings. The information presented will also be useful for inspectors and inspection program managers who want to develop or improve their own procedures.

Field Application of Ultrasonic Phased Array for Structural Evaluation

Curtis Schroeder • *Fish & Associates, Inc.*

Determining the acceptability of a structure when performing an evaluation relies heavily on the confidence in documentation of any existing flaws in the structure. Finding and determining the size of any existing flaws is necessary to perform the fracture mechanics calculations in a fitness-for-service (FFS) evaluation. One of the most significant capabilities of Phased Array Ultrasonic Testing (PAUT) is that it can be used to obtain quantitative flaw sizes instead of attempting to utilize a qualitative estimate based on the amount of reflected sound from conventional UT.

PAUT utilizes multiple element transducers to send multiple signals at a range of angles in order to get a cross-sectional view of indications. Along with PAUT's increased accuracy and flaw sizing abilities, PAUT has been implemented when radiographic testing (RT) cannot be used due to environmental safety concerns. Interest has been shown in extending PAUT usage to replace RT in shop fabrication. Common bridge applications of PAUT are the scanning welds and pins and hangers for internal discontinuities and scanning gusset plates and connection plates for section loss profile.

One of the steps in using PAUT to size flaws is to demonstrate that this technology can be calibrated and applied to field conditions. This includes developing scan plans to ensure sound coverage, calibrating the instrument to account for attenuation, encoding scan data, and interpretation for accurate flaw sizing.

We have applied this technology to various bridge projects to attempt to size embedded flaws including the Sherman-Minton Bridge evaluation in 2011 to measure cracks in butt welds of the tie girder and are currently implementing it to check for hydrogen cracks in the web to flange welds of plate girders. We have performed various US Army Corps of Engineers projects to verify the condition of bridge pins and document the section loss of gusset plates. This research is an ongoing process as we continue to refine the PAUT testing procedures and apply advancements in technology to improve accurate flaw sizing.

Rope Access Investigation and Emergency Repair of the Diefenbaker Bridge Girder Fracture

Frank Block • *Stantec Consulting Services Inc*

Nicholas Cioffredi • *Stantec Consulting Services Inc*

One of the largest in-service bridge fractures to occur in Canadian history was discovered in Prince Albert, Saskatchewan on August 29, 2011. A passing canoeist observed a large crack in the west girder of the Diefenbaker Bridge southbound parallel structure. The crack turned out to be a nearly full height fracture, all but the top flange, of a 6′-6″ (2.0m) tall welded plate girder. The Fracture Critical, 2-girder bridge was immediately closed turning the 4-lane arterial river crossing into a two lane traffic jam with no feasible detour route. The overall project involved an emergency fracture investigation, analysis, repair procedures for the structure's Constraint Induced Fracture (CIF) prone details, strain monitoring, load testing, and long term risk management. Stantec structural engineers immediately began to assess the in-situ stability of the structure. An advanced 3D Finite Element Analysis (FEA) model of the structure including the fracture was developed to determine capacity proving the structure was distributing its own weight but could not handle any vehicular loading, evaluate inspector safety during a detailed investigation, provide risk analysis, and aid the repair design. Stantec's structural engineering and rope access bridge inspection staff trained in fracture critical details, CIF details, and failure history arrived within days to perform an in-depth inspection of the structure and failure zone. SPRAT compliant rope access techniques provided hand on access to engineers. Non-destructive testing (NDT) in the forms of AC and permanent magnetic particle were used to reveal the full extent of the fracture and test similar connection details at other locations for impending fracture. Detailed measurements and photographs of the fracture were taken for further analysis. Detailed inspection of the fracture confirmed the brittle nature of the failure. Photographic mapping of the failure surface aided the analysis and determination of the assumed CIF. Often misunderstood as fatigue, this connection detail limits web yielding resulting in a rapid brittle fracture. Similar welded connections at 344 other locations along each girder of the southbound and northbound structures were inspected for signs of crack initiation.

Information gathered during the in-depth investigation was used for the design of the emergency structural repairs, consisting of a section of girder removed and replaced in its entirety using temporary support jacking towers mid-winter in Northern Canada. Strain monitoring was performed continuously in the girders, and live load testing of the repaired bridge and the un-fractured bridge was carried out to verify load carrying capacity following the repair.

The presentation will summarize the project from fracture to live traffic, historical failure comparisons and is critical for bridge owners, designers, inspection and maintenance staff to understand the details and failure modes. The pictures alone will captivate the audience hopefully increasing retention of this critical detail. Unlike fatigue, warning signs can be limited and failure quick.

7C BRIDGE DESIGN CASE STUDY

Design and Construction of Fresno SR 180 Braided Ramp Design Build Project

San Liang (Sammy) Tu • *Arup*

This presentation presents design and construction of Fresno SR180 Braided Ramp Design Build Project which is located in the city of Fresno, California. Expected to be completed by fall 2013, the Fresno 180 Braided Ramps Project is the first of ten planned design-build demonstration projects authorized by California's Senate Bill No. 4. The project will replace an existing weave section on State Route 180 between State Route 41 and 168, improve flow and reduce access at the freeway-to-freeway connections between 168, 41 and 180. The project includes the constructing of two new cast-in-place post-tensioned box girder bridges, one existing bridge widening, approximately three miles of on-grade ramp connectors, and other associated work. The total construction cost is approximately $50million with a design-and-construct duration of less than two years.

This presentation will introduce following features of this design build project:

1. As a newcomer to the design-build process, Caltrans relied heavily on the project team to help the agency benchmark strategies that could be used on future projects. This presentation will present how the design build team, working closely with the owner (Caltrans), moved the project forward efficiently and seamlessly.
2. The two new bridges, North Bridge and South Bridge, are 4 span cast-in-place post tensioning box girder bridges and are at high skew, with roadway underneath. The team was able to reduce construction cost by shortening the bridge length by 15% for each bridge, and dropping the height of box girder from 8'-0" to 6'-6".
3. The design build team demonstrated the effectiveness of using spread-footing foundations for the three bridges as opposed to the cast-in-place piers historically used by Caltrans, an approach that significantly cut costs
4. To meet the fast track schedule, the design build team adopted a phased construction approach and ensued that each "design package" was completed in accordance with the rigorous construction schedule. It helped to shave several months off of the project timeline.
5. A major challenge of design-build projects is that construction begins before final designs. As such major revisions to design can impact the quality of the final product. Key design items such as post-tensioning were thoroughly analyzed by Arup engineers using 3 independent software, including spline, grillage and finite element models to ensure a reasonable factor of safety in the initial design.
6. Traffic disruption during any highway construction is inevitable. To minimize traffic disruptions, the construction team proactively and efficiently used city streets as staging locations instead of diverting traffic to those city streets.

Precast Girder and Integral Bent Cap for the Sunset Blvd and Skirball Center Drive Crossing Bridges

Evelyn Liang • *HNTB Corporation*

This presentation will describe advantages of the precast girder and integral bent cap system and construction methods utilized to deliver two replacement bridges for the I-405 Sepulveda Pass Widening Project.

7D BRIDGE REHABILITATION

Peter Smith • *T.Y. Lin International*

Caltrans, in partnership with the City of San Diego, is overseeing the seismic retrofit and rehabilitation of the Laurel Street Overcrossing. This National Historic Landmark, also known as the Cabrillo Bridge, was constructed in 1914 for the Panama-California Exposition of 1915. The bridge crosses the SR 163 Freeway and provides the only access for pedestrians and vehicles into the heart of Balboa Park from the west over Cabrillo Canyon. The bridge has been identified for seismic retrofitting and is in need of rehabilitation to repair corrosion and to improve accessibility for inspection. Retrofit and rehabilitation work will start in 2013 and be completed in time for the 2015 Centennial Celebration of the park.

The reinforced concrete bridge resembles a Roman aqueduct and consists of eight independent arch cantilever spans with the following features:

- Total structure length of 769′
- Maximum height of 120′
- Cantilever spans are supported on two 12′ square hollow columns connected by a transverse arch
- Large bin type abutments

The bridge is located in a high seismic zone and analysis indicates the piers lack sufficient displacement and shear capacity. The retrofit strategy is to lock the cantilever spans together to force the bridge to behave continuously and to strengthen the piers. Superstructure and pier retrofitting consists of:

- Removing and reconstructing the concrete at the mid-span cantilever joints
- Longitudinally post-tensioning the bridge superstructure
- Constructing infill shear walls in the piers with vertical post-tensioning

Vertical post-tensioning will extend up to 100′, therefore custom specifications were written for the procedures, mock-up, and testing of the vertical grouting which utilizes thixotropic grout. All of the seismic retrofitting is internal to maintain the historic character of the bridge.

The bridge has spalled concrete and corroded rebar caused by water damage under the deck and at the mid-span joints. Rock pockets from the original construction and seepage of water has been found at the pier construction joints. Portions of the bridge were inspected in order to quantify the amount of unsound concrete which was used in estimating the cost of repair. Destructive and non-destructive testing was performed to determine the material properties of the existing concrete and steel. Inspection of the bridge interior is difficult due to narrow wood catwalks, extensive wood debris, exposed electrical wiring, and steeply eroded slopes in the abutments. Rehabilitation work includes improving access by replacing the original wood catwalk, installing access doors in the piers, grading abutment slopes, and adding interior lighting.

US-2 Moyie River Gorge Bridge Rehabilitation

Dan Gorley, P.E. • *Idaho Transportation Department – ITD*

Kenneth Clausen, P.E. • Idaho Transportation Department – ITD

The US-2 Moyie River Gorge Bridge rehabilitation project required deck rehabilitation, corrosion mitigation, spot painting, substructure repair, and slope repair. The department used several innovative technologies on this project for evaluation, design, and repair. Ground Penetration Radar (GPR) was used to assist in evaluating the deck condition. Anode protection was used for corrosion mitigation in the superstructure and substructure. The project also included the use of Polyester overlay as a best fit application due to the condition, deck design, and to limit the weight on the bridge.

The US-2 Moyie River Gorge Bridge is a 1223′ steel plate girder and steel truss bridge that spans the 450′ deep Moyie River Gorge. US-2 is an East-West route in the Northern United States which cuts through the beautiful Northern Idaho Panhandle and is approximately 50 miles south of the Canadian border. The bridge is a 2 lane highway which is 28′ curb-to-curb. The structure has 6 spans and from West to East consists of 2 steel plate girder simple spans 110′ long, a 3 span 918′ long steel truss, and 1 steel plate girder simple span 110′ long.

The deck consisted of 6″ light weight concrete with a 1″ monolithic high density wearing surface. Additionally, the deck had a 1 to 2 inch plant mix asphalt overlay. The surface of the deck was in poor condition. Several core samples showed that there was not significant delamination near the top layer of deck steel, however; the light weight concrete was very easy to cut when cores were taken. Hydro demolition was a concern for the light weight concrete. Additional evaluation with GPR, GSSI BridgeScan system, and infrared thermography was used to see if limited deck removal and a Polyester overlay would be the best solution. This would also allow less weight to be added to the superstructure.

Areas of the deck near the joints and portions of the substructure columns showed severe corrosion in the reinforcing steel. Two styles of Vector Anodes were installed to mitigate the corrosion. Additionally, six joints on the continuous truss were eliminated to stop corrosion issues occurring on the truss below the joints.

The most challenging repair on the structure was the concrete column hinges. Span 2 consisted of 110′ steel plate girders pinned at both ends. The span was pinned on top of pier 1 at 103′ in height and then pinned on top of 24′ columns connected to the top of 126′ tall pier 2. The columns had deteriorated concrete hinges at the bottom, just above the top of the pier. The hinges took most of the rotation due to temperature movement in span 2. A steel frame was used to support one end of the span while the 2 columns were repaired in 4 stages.

Additional repairs included 20,000 ft2 of spot painting on the steel plate girders and the steel truss as well as steep slope stabilization with hand placed rip rap. Parts of the superstructure drainage system were replaced. This presentation will include innovation successes and lessons learned during the rehabilitation of the structure.

8A BRIDGE DESIGN POLICIES

Stability of Straight Steel Plate Girders During Construction

Robert Gale • *Buckland & Taylor*

The improving performance of structural steel, the efficiency of plate girders, and growing span lengths for these bridges increases the critical nature of girder stability during construction. Permanent design may not anticipate the un-braced lengths that could occur during girder erection and deep un-braced plate girders are inherently unstable. Consideration must be given during transport, fit-up, and erection of individual plate girder elements to avoid overstress and/or instability. Also, the live and dead construction loads that act upon the assembly during erection may result in instability of the partially completed structure.

During construction, the complex operation of erecting plate girders is often left solely to the general contractor and/or their subcontractor to plan and execute. Stability of the girders, for all phases of erection until the bridge deck becomes composite, lies within the means and methods of a carefully planned erection procedure. Considerable engineering judgment as well as practical experience, and knowledge of construction techniques, are all required to make suitable and safe erection procedures.

The presentation gives an overview of analysis methods for determining the stability of plate girders during erection, as well as techniques and considerations in providing temporary stability of plate girder elements.

Analysis Of Curved And Skewed Steel Girder Bridges During Construction

Domenic Coletti • *HDR Engineering*

The recently completed NCHRP Research Project 12-79 investigated various analysis methods for curved and skewed steel girder bridges. This presentation will discuss the characteristics, attributes, and limitations of one of the analysis methods studied in the project, namely, the 2D-grid analysis methods. Based on these studies, improved modeling techniques that can be implemented in 2D-grid analysis for a better representation of the structural behavior of steel girder bridges during construction are introduced. Studies of bridges with challenging geometries are presented to show the implementation of the proposed modeling techniques and their benefits.

8B GEOTECHNICAL DESIGN

Geotechnical Challenges of the S. Holgate Street to King Street Viaduct Replacement Project, Seattle, WA

James Struthers • *WSDOT*

The S. Holgate Street to S. King Street Viaduct Replacement project is part of the Alaskan Way Viaduct Replacement Program and replaces the southern mile of the aging Alaskan Way Viaduct that runs along downtown Seattle. The project included construction of two, three-lane, side-by-side bridges about 1,890 feet long with 150- to 800-foot-long approach embankments. This presentation will focus on the geotechnical challenges of the project and how they were successfully addressed through the use of innovative design and construction techniques.

Geotechnical challenges in the project were driven by project staging and soft subsurface soil conditions. The subsurface geology included up to 240 feet of recent native and fill deposits over dense glacial deposits. The recent soils were anticipated to liquefy during design seismic event to depths of up to 120 feet. Liquefaction-induced downdrag forces were mitigated by deepening the drilled shafts as much as 150 feet below the ground surface. To mitigate lateral spreading forces, ground improvement cells were constructed around the drilled shaft foundations. These cells extended to depths of 50 to 100 feet around eight foundations that were within the estimated lateral spreading zone. Due to staging constraints, the ground improvement was installed in two phases using deep soil mixing. Jet grouting was used to join the two phases.

The southern portions of the bridges were supported by large-diameter steel pipe piles where the soft soil deposits were too deep to allow for use of drilled shafts. Some of the driven piles for the northbound bridge were located within 50 feet of the existing viaduct, which had to remain open to traffic during construction. During the design phase, it was identified that vibrations due to pile driving might damage the adjacent viaduct in areas where more than 10 feet of pile penetration into dense glacial soils was required. For these locations, an innovative composite pile system was developed to allow for isolation of the vibrations during pile driving. A test pile program including vibration and settlement monitoring was implemented to confirm that pile driving would not adversely affect the existing viaduct. During production pile driving, no traffic closures were required and no settlement or damage to the viaduct occurred.

The bridge approach embankments (up to 28 feet high) had to be constructed in three phases to allow for maintenance of traffic. Stability analyses indicated that embankments constructed with standard WSDOT backfill would not be stable for heights greater than 15 feet during the design seismic event. In addition, settlement analyses indicated that 6 to 12 inches of settlement could occur with each successive embankment phase. To mitigate embankment settlement, provide for global stability during a seismic event, and to expedite the construction schedule, lightweight fill (expanded polystyrene) was used to construct the approach embankments.

The geotechnical challenges of the project were successfully mitigated by WSDOT and the design team with innovative design and construction approaches. The project was successfully completed in October 2012 within budget and one year ahead of schedule.

Wishkah Bridge Replacement-Designing for Significant Landslide Movement with Conventional Materials

Anne Fabrello-Streufert, SE • *KPFF Consulting Engineers*

Jason Pang • *KPFF Consulting Engineers*

Aaron Olson, PE • *KPFF Consulting Engineers*

Wishkah Road crosses Cedar Creek approximately 20 miles north of Aberdeen, WA in Grays Harbor County. Large scale landslides are prevalent in the vicinity of the bridge and was suspected to be the cause of damage to the 30-year old timber pile and precast concrete girder bridge. The southeast abutment slid horizontally toward the creek and heaved upwards. This movement led to distortion of the bridge deck, shearing of the timber piles, and damage to the guardrails. Consequently, the bridge was load restricted to 3 tons. Continued movement would have forced closure of the bridge and eliminated primary access to the City's water supply.

Geotechnical investigations found the landslide slide plane deeper than expected and that that slide movements were large and complex. A full characterization of the landslide would have required a long study, which was beyond the funding and timeline available. With the limited resources available, the expected movements were conservatively estimated based on displacement of the existing structure, inspection reports and slope inclinometer readings for design of the replacement structure. The estimated movement over a 20 year period was 40 inches longitudinally, 20 inches transversely, and 3 inches vertically.

Designing the foundations to withstand landslide forces was neither practical nor feasible. Instead the bridge was designed to accommodate landslide movements. The southeast abutment, supported on the landslide, consists of a spread footing with PTFE-stainless steel sliding bearings. The land mass, along with the footing, is allowed to move beneath the bridge while the superstructure remains in place. Because the southeast abutment provides no restraint, other than vertical support, all lateral resistance is provided by the northwest abutment which is situated on stable soil. As a consequence, the north abutment needs to resist significant torsional seismic forces, something uncommon in standard bridge design. Using principles common in waterfront pier design, the north abutment employs a multidirectional batter pile pier cap system to resist these forces.

The superstructure carries a 16 foot wide roadway and is composed of precast prestressed deck bulb tee girders spanning 90 feet with a CIP deck. The predominant seismic behavior is a "wagging" motion because lateral resistance is provided by only one abutment. One end of the bridge remains restrained while the other swings back and forth in the transverse direction. In order to keep the superstructure intact during an event, a 5-inch thick cast-in-place concrete deck and several full-depth intermediate diaphragms were utilized to tie the girders together.

The superstructure is connected to the northwest (fixed) foundation using two high-strength rods anchored to the abutment. The rods were designed to provide restraint to keep the superstructure in place during landslide movement and a design earthquake. Should the forces in the rods exceed their capacity; the rods will act as the fuse element protecting the batter pile foundation from damage.

Shaft Base Grouting-Perching Deep Foundations in Specific Soil Layers

Stuart Bennion • *BergerABAM*

Shaft base grouting is a process to preload and improve the bearing materials below the shaft base. Bridge shaft foundations are generally placed to a depth where skin friction and end bearing pressures are sufficient to support the bridge design vertical loads. In some cases, a dense soil layer is sitting on top of a deep layer of soft or compressible soil. A shaft that has to extend into this soft soil will generally need to extend through the full depth, until it reaches a dense layer deep down. Restricting the shaft base to this upper layer allows for simpler construction and significant cost savings for each shaft constructed. Base grouting is necessary, in this case, to build up the shaft resistance and make sure that the shaft does not plunge into the soft soil layer.

The SR522 Snohomish River bridge shafts at Piers 7 and 8 had a medium dense soil layer on top of a compressible clay/silt layer. Developing the shaft resistance in the compressible material was difficult and the shaft depth would have been beyond the 165 foot geotechnical boring. About 160 feet below the surface is an artesian lens with increased water pressure. A shaft design extending through this artesian layer added complications. Restricting the shaft tip to this upper layer would not develop sufficient resistance for the bridge design forces. The Geotechnical Engineers required the shaft tip to stay at least 10 feet above the compressible layer to avoid settling into the compressible layer. Designers traded off the cost of base grouting against the cost to extend the shaft into these deeper dense layers. Base grouting was the tool selected to accommodate the existing conditions and bridge design requirements.

The process of base grouting shafts requires experienced contractors who understand the subtleties of application, shaft behavior, and how to adjust the work to accomplish the contract requirements. Soil properties, geologic conditions, and subsurface conditions are critical for the contractor to develop a successful plan. As the nature of the work is at the base of the shaft, were you cannot visibly inspect the process, this understanding and proper techniques can make or break the success of base grouting. Contract requirements need to place the risk of the work on the party that can mitigate the risk the best.

This presentation will look at the process of designing and constructing a shaft that utilizes base grouting. It will focus on lessons learned from contract language, base grouting techniques utilized, and how risks/problems were mitigated on the Snohomish River Bridge project.

8C BRIDGE DESIGN CASE STUDY

The Two Medicine River Bridge: Montana's First Post-tensioned Concrete Box-Girder Bridge, Glacier, MT

Tony Kojundic • *Silica Fume Association*

The new $25M Two Medicine River Bridge opened September 2012, is Montana's largest bridge to date, and the DOTs first cast-in-place, segmental post-tensioned concrete-box girder superstructure. The new 1160-ft long bridge replaces one built in 1941, which is now both structurally deficient and functionally obsolete. The bridge carries US Highway 2, the northern-most, east-west highway crossing the United States and the Rocky Mountains. The bridge links a commercial corridor integral to local residents of the Blackfeet Reservation and vital to US national security and trade. Without this bridge, the resulting detour for traffic would be 370 miles.

Due to the volatility in steel and concrete prices during the planning stages, the DOT bid both designs and encouraged the contractor to bid on both alternatives. In addition to a construction cost the bids requested the number of days of construction to complete the project. Factoring in a cost per day of construction the DOT was able to get the best value in capital cost, while minimizing the inconvenience to travelers.

Taking into account the harsh winters in northwest Montana, and the need for extending the service-life of the new bridge, the specifications called for a high-performance concrete through-out the structural elements and the deck alike. Design strength was 6 ksi and the permeability requirement was <1500 coulombs at 28 days based upon AASHTO T2707 Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete. The contractor also needed early-strengths to proceed with early post-tensioning of the individual cells to stay on construction schedule. Typical concrete properties reached compressive strengths of 9-10 ksi at 28 days and permeabilities of <1300 coulombs at 28 days (7-800 coulombs at 56 days).

This presentation will highlight the design features and concrete properties that will make this bridge safer for residents and visitors to the adjacent Glacier National Park for many years to come.

The First Thermoplastic Bridges Located in U.S. Highways

Vijay Chandra, PE • *Parsons Brinckerhoff*

John S. Kim, Ph.D, PE • *Parsons Brinckerhoff*

A sustainable and innovative thermoplastic construction material made of recycled plastics was introduced to the market about two decades ago. The thermoplastic structural composite produced by Axion International was initially utilized for railroad ties and has gradually extended its application to bridge structures. Including its first bridge application in 1998, most thermoplastic bridges were located within non-national highway system such as military bases or state parks where the AASHTO design criteria were not strictly required. With continuous improvement in material and design, two thermoplastic bridges have been constructed in the U.S. highway system in 2011 and 2012.

The first thermoplastic bridge constructed in the U.S. highway system was opened in the State of Maine in December 2011. The new bridge replaced the existing concrete culvert as the waterway was widened from 3 feet to 12 feet to resolve frequent flood issue in the region.

The two-lane bridge is approximately 14 feet long and 26 feet wide. Nearly entire bridge components including girders, piles, pier caps, backwall, and wingwalls are made of recycled post consumer and industrial plastics that would otherwise be discarded into landfills. The bridge was designed for the AASHTO HL-93 vehicular load.

The bridge deck consisted of multiple 18″ I-beams placed side-by-side. For accelerated bridge construction, the bridge deck was pre-fabricated in 3-beam clusters connected with 1″ diameter tie rods before transported to the bridge site. Because the skid resistance of the thermoplastic deck surface is not enough for highway vehicles, the entire bridge deck was covered with 4″ aggregate base and 3″ asphalt concrete overlay.

Due to erratic soft soil layers and uncertain skin resistance of the pile, the 12 inch diameter thermoplastic piles were driven to a firm bearing stratum ignoring the skin capacity. Pile installation was performed by using a vibratory hammer first and driving to final set criteria utilizing a diesel impact hammer. Since the thermoplastic piles are produced in length of 45 ft, some of them needed to be spliced using a clamping steel pipe connector with through-bolts on each splice piece.

The contractors had a learning curve since this material was new to them. With extensive technical understanding and experience in bridge design, the PB's bridge design team was able to promptly respond to the construction challenges to complete the bridge construction in time and within the budget.

Another thermoplastic bridge constructed in the national highway system was opened to the public in Ohio in December 2012. The Logan County was awarded a federal fund of the Innovative Bridge Research and Deployment Program to replace an aged timber deck bridge using the sustainable thermoplastic material.

The Logan County Engineer's Office utilized county staff to construct their first thermoplastic bridge with an exception of pile driving. The bridge over Onion Ditch was built in an accelerated manner, called Accelerated Bridge Construction (ABC) that is presently being recommended by the FHWA to be nationally employed. To expedite the construction process, each beam cluster that consists of two 18″ I-beams and cover plates on top of the beams was prefabricated at the factory and then shipped as one piece to the bridge site. Owing to prefabrication process and easy handling of this light weight thermoplastic composite, it took only three days to construct the bridge superstructure.

The bridge has a 25° skew and is approximately 25 ft long and 25 ft wide. The PB's bridge design team successfully developed the world's first thermoplastic composite section that primarily consisted of the 6″ deck panels and 18″ I-beams. This composite section enabled the bridge span length to reach up to 25 ft, which is the longest in its kind to support the current AASHTO HL-93 load. The same bridge team also designed the world's first guardrails made of recycled plastics that satisfied the AASHTO barrier requirements for TL-2 level.

The abutment backwalls consisted of 3-inch thick and 12-inch wide planks screwed into pilings that were driven in a line 3.25 ft on center at each abutment. Since the total required pile lengths ranged from 10 ft to 15 ft, no pile splicing was needed for this bridge. Like the Maine bridge case, the semi-integral abutment bridge design concept was utilized to effectively support all the bridge loads specified by the current AASHTO specifications. The bridge superstructure was designed not to exceed a deflection of Span Length/425 under the HL-93 load. The bridge deck surface was overlaid by waterproofing membrane, 4" aggregate and 3" asphalt concrete overlay.

This new sustainable material can provide a cost-effective solution to the currently deteriorating infrastructure and at the same time provide an excellent solution to the environmental issues of plastic waste. Its use will undoubtedly increase as more research and development efforts are continuously made to enhance the material properties and manufacturing technologies.

This paper will present two thermoplastic bridges located in the national highway system and will also discuss each bridge's unique design features such as application of semi-integral abutment mechanism and utilization of composite action between deck and girders.

8D PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

Prefabricated Bridge Elements and Systems in Idaho

Kenneth Clausen • *ITD*

The presentation is on the recent use of PBES on three bridges in Idaho; a 72' single span prestressed concrete bridge over Johnson Creek, a 79' single span prestressed concrete bridge over Trestle Creek and a 340' 3-span steel bridge over the Weiser River. Each of these bridges utilizes precast substructure elements.

Johnson Creek Bridge is located in a remote area near Yellow Pine Idaho and provides access to the Johnson Creek Airport. The bridge includes precast abutments, wing walls, and girders all founded on steel H-pile. The Johnson Creek Bridge project will show an environmental side to PBES along with some challenges regarding ABC construction. This project will highlight some environmental challenges to the ABC construction schedules when dealing with endangered fish and inclement weather. The project also highlights the effects of changing industry project expectations relating to cast-in-place contractors and precast manufactures.

Trestle Creek Bridge is on SH-200 in northern Idaho and includes precast abutments, girders, approach slabs and precast concrete block wing walls. The new bridge is replacing existing deteriorated bridge and requires two stage construction with two lanes of traffic available through construction site at all times. Trestle Creek is a spawning ground for bull trout and therefore considered environmentally sensitive stream. In-water construction activities are limited to 7 weeks only between July 7 and August 23. Both stages of the substructure, including riprap, have to be installed in this time frame. The unique aspect included precast abutments composed of four segments each and assembled with both horizontal and vertical joints, precast approach slabs and sleeper beams, and use of concrete block gravity retaining walls instead of more conventional wing walls.

The Weiser River Bridge on US-95 is a stage constructed three-lane bridge that includes the use of precast pier columns and pier caps. The columns are supported on cast-in-place pile caps constructed within sheet pile cofferdams. The first stage of the pier caps is precast and the second stage is cast-in-place. The superstructure consists of conventional steel plate girders with cast-in-place deck. The abutments are cast-in-place integral abutments with approach slabs.

These projects highlight Idaho's use of PBES including both the advantages of these types of systems as well as the typical problems that arise during construction.

Construction Difficulties in Rural Arizona

Amjad Alzubi • *ADOT*

It was the norm for big 20-30ft trees to flow downstream during flooding events in South Eastern Arizona. The existing US 191 San Francisco River Bridge, constructed in 1960, would trap those large trees between its steel I-Girders. After years of damage to the superstructure, and multiple overtopping's of the bridge; in 2008, the Arizona DOT decided to replace the bridge with a Concrete Closed-Frame Continuous Slab Bridge

The bridge is located on the town of Clifton main street with businesses on both sides of the highway, US 191 which is a vital highway in the region, as it connects Clifton to Morenci, where Freeport-McMoRan Copper and Gold operates one of the largest copper mines in the world.

Since the bridge location is within the town of Clifton, changing the vertical profile was not an option, but there was a need to decrease the depth of the superstructure to allow water to flow under with less obstruction. The Bridge selection Report recommended a slab bridge with a scour floor as the best option. In addition, Construction was to be completed in phases to keep bridge open for traffic.

Construction issues varied from high water table, hot springs, mine tailings, the proximity to the AZER RR Bridge (20ft upstream), and the RR concerns about the new bridge creating scour issues for their 100yr old RR Bridge. After 2.5 years in construction, numerous design changes and additions, newspaper articles, town council resolution, and an additional $1M in construction costs; the project was completed.

Seismic Performance of Bridge Systems with Innovative Design: Deployment of Research

M. "Saiid" Saiidi • *Professor of Civil & Environmental Engineering, University of Nevada-Reno*

Brian Nakasoji • *University of Nevada*

Jedediah Bingle • *Washington State Department of Transportation*

The primary seismic design objective for standard bridges has been collapse prevention. The sufficiency of this objective is being reconsidered by researchers and engineers. Collapse prevention is certainly necessary but insufficient with respect to the overall performance of the highway network and its post-earthquake serviceability. Therefore, the seismic design objectives need to be two-folds: (1) resist seismic forces and displacement demands during earthquakes, and (2) improve resilience of bridges so that they are operational or require only minor repair after earthquakes.

The first objective can be satisfied with proper design and detailing of members and connections with conventional or innovative materials. To accomplish the second objective residual displacements and plastic hinge damage should be reduced substantially. One method to address both aspects of the second objective is to use shape memory alloys (SMA) and high performance concretes (HPC) and grouts. Engineered cementitious composites (ECC) are a class of grouts with high tensile strain capacity that makes them resistant to damage. Recent research on combination of SMA/ECC has demonstrated that it is possible to accomplish both objectives.

These materials are being adopted in the construction of SR-99 on ramp structure in Seattle, Washington. The bridge consists of three spans and two square columns. Due to the uniqueness of the columns of this bridge, limited additional testing and modeling studies are being conducted at the University of Nevada, Reno. The testing is expected to be completed in Summer 2013. The presentation will provide background information about the seismic performance of SMA/ECC columns and the specific studies and seismic design aspects of the SR-99 structure.

9A CABLE SUPPORTED BRIDGES

Fabrication of the Deh Cho Bridge Pylons

Paul King • *Rapid-Span Structures Ltd.*

Deh Cho Bridge – Northwest Territories, Canada: The Deh Cho Bridge is a long–span steel truss structure crossing the Mackenzie River in the Northwest Territories. After over 30 years of planning and debate, the structure is now complete; providing a year-round link on the Mackenzie Highway to access Yellowknife. It was opened to traffic in December of 2012.

The main span is an extradosed cable supported structure supported by steel A-frame pylons.

The pylon legs are a six-sided, stiffened plate, hollow section that tapers in dimension along its length. In addition, legs are bowed to allow sufficient clearance for vehicles at road level. The project requirements had stringent requirements on the dimensional tolerances of the fabricated pylons to ensure that deviations in the geometry did not introduce unanticipated forces into the structure and to ensure the clearance for traffic at road level was not encroached. The complexity of the pylon geometry coupled with the challenges of fabricating these fracture critical weldments made this a unique and challenging fabrication project.

This presentation reviews the steps and many challenges that were encountered during the fabrication process. It will also review the advanced welding processes and fabrication techniques were used to minimize weld distortion and maintain overall geometry while simultaneously maximizing the welding and fabrication efficiency. The project illustrates how modern fabrication techniques can make steel a cost-effective choice for cable-stay bridge pylons.

Innovative Methods for Inspection of Cable-Stayed Highway Bridges, Old and New

Scott Wyatt • *KPFF*

Cable-stayed bridges were chosen with greater frequency for US highway and light rail transportation corridors, starting in the mid 1990's. Today, major western US stayed spans are under construction or in design. The western US also happens to be home to an inventory of several older stayed highway structures. Focusing predominately on the stay cable systems, this presentation will provide an overview of how experienced cable stayed bridge inspectors planned, scoped, and conducted in-depth inspections of a pair of structures; the 30-yr old Hale Boggs Mississippi River crossing in Louisiana and the 10-yr old 6th Street Viaduct Bridges in Milwaukee. Inspection of the older Louisiana structure lead to the finding that complete replacement of the cement-grouted parallel wire stay cable system was warranted; corrosion protection system defects and corrosion of its earlier generation tension elements drove that outcome. The newer Milwaukee structures' cable system design reflects improved modern-day stay cable design, corrosion protection technology and well-executed erection methods. Methods and findings from both these inspection programs will be of interest, since the stay cable systems are generations removed from each other, and reflect the wide ranging age of the present and future bridge inventory.

Nondestructive inspection techniques were used extensively to assess condition of cables' main tension elements, whether old or new. Soundness and integrity of the cable tension element is critical for sustaining bridge safety, but these are obscured from inspectors' view by as many as 4 layers of corrosion protection. The presentation will focus on the latest inspection techniques for stay cables, pylons and deck level anchorages. Procedures for arm's length identification of corrosion protection, anti-vandalism and damping system features and defects will be discussed, as will nondestructive examination of anchorages, cable free length and grout voids, and global cable condition assessment using the vibration method. Size and height of stayed bridges, and superstructures' complexity pose unique inspection challenges associated with safe inspection, access, and traffic control; the presenters will also discuss access techniques and logistics.

The presenters have accumulated unique experience resulting from in-depth, hands-on inspection and non-invasive condition assessment of 15 stay-cable supported bridges in the US and UK, since 1998.

9B BRIDGE PROJECTS

Gusset Plate Triage Analysis for Steel Trusses in Washington

Patrick Gallagher • *Washington State DOT*

In response to the collapse of I-35W Bridge in Minneapolis on August 1, 2009, states are required to evaluate the structural capacity of steel truss gusset plates in their load rating efforts. This presentation would describe the implementation of a project conducted by the University of Washington and WSDOT to rapidly evaluate steel bridge gusset plates; the "Triage Evaluation Process."

The triage evaluation process is a relatively quick evaluation process designed to rapidly identify which gusset plates are of most concern, and which ones are of no consequence to the load rating of a bridge. It requires accurate structural modeling of the bridge to determine truss member end forces, and then a rather quick and effective analysis process using tools developed by the University of Washington. Artificially low rating factors are given to the gussets. And when those low rating factors control the rating, a more accurate and time consuming rating method is considered only for those portions identified as inadequate in the triage evaluation. This saves engineering time and effort, saving tax payer money in engineering costs, while quickly ensuring the bridges they drive on are safe, or to which degree WSDOT needs to be concerned.

The presentation will describe the significance the collapse of the bridge in Minneapolis had on WSDOT's engineering needs, and the response Washington State has taken. The task for evaluating so many steel bridges is enormous. Attention will be given describing how to tackle the task of evaluating hundreds of steel bridges across Washington State in as little time as possible. It will briefly describe how to model a truss designed in an era gone by, with modern tools. The I-90 crossing at Vantage will be used as an example.

History of Accelerated Bridge Construction at BergerABAM: 50-Plus Years of Innovation

M. Lee Marsh • *BergerABAM*

James S. Guarre • *BergerABAM*

Robert F. Mast • *BergerABAM*

Greg A. Banks • *BergerABAM*

Accelerated Bridge Construction (ABC) methods have been utilized by BergerABAM for more than 50 years. The key success factor on ABC projects is using the optimal blend of precast concrete and cast-in-situ concrete components on bridge type projects.

ABC techniques began in the mid-1950s with the development initially used to span up 120 feet. Use of precast concrete bridge girders accelerated bridge superstructure construction, and precast substructures were used occasionally, as well. Several noteworthy bridges were built for the logging industry, and these included precast superstructure, precast substructure, and spliced girders.

Subsequently, ABC methods were used on transit/people-mover projects, and bridges in Disney World, Vancouver, BC, and Getty Center in Los Angeles made significant use of ABC. These projects each made use of ABC in slightly different ways, highlighting the importance of creativity and innovation in addressing job-specific challenges. Additionally, marine applications of ABC techniques have provided fertile ground for cross-pollination of ideas with the bridge community. At least one "bridge", the Kenmore Interceptor sewer, which is completely hidden beneath Lake Washington, was built entirely of precast elements - underwater.

More recently, BergerABAM was selected to lead a FHWA Highways for LIFE technology partnership project in collaboration with WSDOT, the University of Washington, Concrete Technology Corporation, and Tri-State Construction to develop precast concrete bent substructures for use in high seismic zones. These techniques were utilized on a demonstration project bridge over I-5 and on a bridge project spanning across SR520. This project highlights the effectiveness of collaboration between bridge-delivery organizations in terms of fielding ready-to-deploy techniques for ABC.

This paper will present a broad-based collage of bridge/transit projects demonstrating the increasing use of precast concrete components over 50 years to shorten on-site construction time and improve bridge delivery.

9C BRIDGE DESIGN CASE STUDY

Washington Street Overcrossing-Accelerated Bridge Construction Methods: Concept to Completion

Andrew Howe • *OBEC Consulting Engineers*

Oregon 213 at I-205 is a busy highway carrying more than 65,000 vehicles per day. Increased local demand that is anticipated from development in Oregon City would have burdened the traffic signals near the existing interchange beyond functional capacity. In preparation for future development, the City of Oregon City took the first steps to ease congestion thanks to Oregon Jobs and Transportation Act funding and ODOT's cooperation.

Grade separation of Washington Street and Clackamas River Drive from Oregon 213 was required to eliminate left turns and cross traffic. With Oregon 213 located on a raised embankment, the grade separation took the form of a bridge where none previously existed. To meet this need, the design team faced the challenge of getting the bridge completed while minimizing traffic impacts on this critical route.

After a study of the alternatives, the design team found that rather than constructing a bridge in stages (under traffic, and with long duration lane closures), accelerated bridge construction (ABC) with a short duration closure of the highway would better meet the needs of the project owners and the traveling public.

The 130-foot-long by 112-foot-wide skewed bridge would be constructed alongside the highway on a temporary foundation and rolled into place. The concept isn't new, but it is most commonly executed where a gap for the bridge already exists. Here, the existing embankment needed to be removed to make room for the new structure.

A shoring system was developed to facilitate construction of the foundations under traffic with night time lane closures, culminating in an intensive public information campaign and a dramatic four-and-a-half day closure of the highway. Time-lapse video captured the well-orchestrated removal of embankment, the positioning of the five-lane-wide bridge, and the re-opening of the highway to traffic.

This construction concept drove design decisions and details nearly every step of the way. Temporary shoring and bridging was designed so that the foundation excavation could be opened each night and closed each morning. The superstructure type (steel) was selected due to its light weight. End cross frame and diaphragm design was based on the need to jack the structure up and roll it into place. Precast concrete end panels were developed to quickly connect to the approach roadways. Soil nail retaining walls were used under the bridge to allow "top down" excavation for the new roadway.

Ship & Barge Collisions with Highway Bridges

Michael Knott • *Moffatt & Nichol*

Recent decades have demonstrated the potential vulnerability of major highway bridges to catastrophic collapse due to extreme event loads, including natural events (storm surges, scour, seismic), accidental events (vehicle and vessel collisions), and intentional events (terrorist attacks). The presentation will provide an overview of ship and barge collision with bridges over navigable waterways using lessons learned from historical accidents and bridge collapses; updated risk analysis procedures in the AASHTO Vessel Collision Design of Highway Bridges, 2nd Edition 2009 for both new and existing bridges; application of global and local collision loads to bridge substructures; and provide examples of typical pier protection systems for bridges (fenders, pile-supported structures, cellular structures, and protection islands). The authors were the principal investigators for the AAAHTO Bridge Code requirements for vessel collision and teach a 2-day short course on the topic for NHI/FHWA.

9D BRIDGE INSTRUMENTATION

Force Monitoring of Post-tensioning Tendons and Cable Stays in Bridge Structures

Shahidul Islam • *Dywidag Systems International*

The Maintenance of infrastructures has been of particular concerns and responsibility of the engineering community. As the world's infrastructure expands and existing infrastructure ages, monitoring and evaluating the structures have become more significant than ever. It is crucial to determine the behavior of the structure under various loads and environmental effects. A number of efforts were made to instrument bridges for the purpose of structural health monitoring and assessment. Non-destructive testing (NDT) has grown into a reliable alternative to meet these requirements. However, there are significant problems among the available NDT technologies, especially for monitoring the force in tendons and cables in bridge structures. High cost, complicated equipment and the limitation of space often prevent the NDT methods from being implemented. DYWIDAG-Systems International (DSI) has been involved in the development, testing and utilization of DYNA Force® sensors to measure the force in the tendon/stay during construction and at any time during the lifetime of the structure. The monitored response will demonstrate how the post-tensioned tendons/stays are intact and effectively serving within the environmental conditions encountered in the structure. This paper will describe many examples of the applications where DYNA Force® sensors had been used in the United States and overseas.

DYNA Force® sensors are manufactured based on the magneto-elastic properties of ferrous material. A readout unit is designed to magnetically energize the steel through the sensor and measure the response of the steel to the process. The readout unit then converts the response into a direct force reading. The force reading can be collected manually, automatically and also remotely. They can be used for bare, epoxy-coated, galvanized and greased-sheathed steel in bonded, un-bonded, grouted or un-grouted length of the tendon. In addition to the long-term monitoring benefit of using the DYNA Force® system, it may also be used to check the load during stressing to address the safety of the structure. It may eliminate the use of large equipment during a friction test and the need of lift-off operation. It may also eliminate the use of large load cell at anchorages and eventually reduce the pocket depth.

DYNA Force® system has received attention in terms of accuracy, its performance, ease in installation, durability, and cost effectiveness. It has been used in many bridges, buildings and geotechnical applications. Its application in Penobscot Narrows Bridge (Maine), Harbor Drive Bridge (San Diego), Wacker Drive Bridge (Chicago), Wade Bridge (Pennsylvania) and Pont Champlain Bridge (Canada) will be discussed.

Images at Depth-The Use of Acoustic Imaging on Large River Crossings: A Case Study

Jeff Rowe • *Infrastructure Engineers*

Since the mid 1980's, the Federal Highway Administration (FHWA), through the National Bridge Inspection Standards (NBIS), has required states to perform a visual or tactile underwater inspection of bridge substructures located in more than 4 feet of water. For a vast majority of the states, this only requires the inspection of these substructures in ponds, lakes, streams and small rivers. Not so with the Louisiana Department of Transportation and Development (LA DOTD). Being at the "downstream" end of the delta region of the country, the LA DOTD has some of the largest bridges, located in some of the fastest flowing and deepest waterways in the nation. Bridges over the Mississippi and Red Rivers have massive piers (some nearly 200 feet long), in water depths exceeding 100 feet and flows routinely exceeding 10 to 15 feet per second. Fulfilling the requirements of the NBIS for 100 percent visual/tactile underwater examination is next to impossible, if not impossible, in these turbid and zero visibility rivers.

Facing evaluation of the NBIS requirements through the FHWA's Metrics Program, the LA DOTD decided to approach the FHWA with a proposal utilizing a newer technology—acoustic imaging. The proposal was to acoustically scan dozens of larger bridges, review the scans to identify areas of deterioration and scour, and then have commercial divers only investigate those specific areas of potential deterioration. As this would be a first for the FHWA—allowing the wide use of acoustic imaging as a substitute for a 100 percent underwater inspection—several bridges were included that validated the technology and determined its limitations. The scanning and underwater inspection of LA DOTD's largest bridges and "technology-validation structures" has recently been completed.

The presentation will present the results of the scanning and diving; identify where it worked well and where it didn't; provide comments by the LA DOTD and the FHWA on the use of this technology; and give suggestions for the use of acoustic imaging in the future.

KN FRIDAY CLOSING KEYNOTE

Whence and Whither Seismic Design? Past and Future Perspectives on Bridge Seismic Design

M. Lee Marsh • *BergerABAM*

It is useful to understand how bridge engineering practice came to be what it is today, to understand what has influenced that practice, and then to anticipate where our practice might be heading. This presentation will provide a high-level overview of significant historical developments in earthquake engineering and the seismic design of bridges, including developments in related practice areas, developments in bridge research, as well as lessons learned from significant earthquakes. An overview of the current state-of-practice for seismic design will be summarized, and in conclusion the presentation will provide a perspective on what the future may hold for seismic design of bridges, including performance-based seismic design and its effects on minimum design standards.

Bridging the Gap Africa

Kelley Rehm • *AASHTO*

Bridging the Gap Africa, Inc. works with marginalized groups of people in sub-Saharan Africa to build bridges that provide people with safe crossings across dangerous rivers, gullies, and ravines. In every instance, our bridges immediately improve the quality of life in these communities as their daily foot-travel burdens are lessened and their risks of losing loved ones are greatly reduced.

- Our bridges transform lives by:
- Allowing children to reach schools safely, every day.
- Improving community access to healthcare.
- Reducing travel time to market centers.
- Preventing accidental death from drowning.
- Eliminating crocodile and hippo attacks.