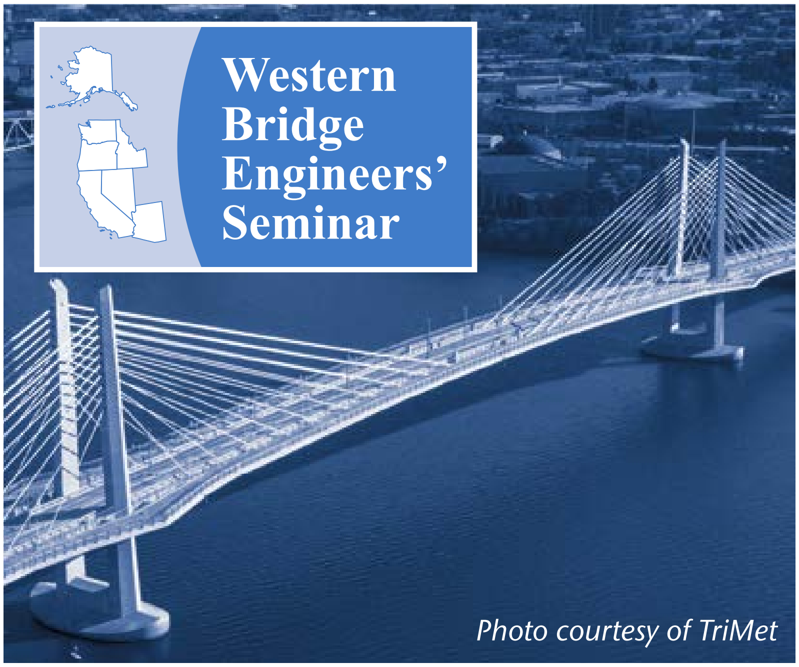

Photo courtesy of TriMet

INNOVATIVE SOLUTIONS THAT STAND THE TEST OF TIME

Portland Marriott Downtown Waterfront
Portland, Oregon

Seminar managed by:

Conference Management
Washington State University

K1 KEYNOTE SESSION

Overview of the OR-18 Newberg – Dundee Bypass Project

Matthew Stucker • *Oregon Department of Transportation*
Robert Goodrich • *OBEC Consulting Engineering*
Tony Snyder • *Oregon Department of Transportation*
Scott Schlechter • *GRI*

The purpose of the OR18: Newberg-Dundee Bypass Project (NDBP) is to improve mobility and safety for highway traffic through Newberg and Dundee and to relieve congestion by reducing truck and passenger vehicle traffic on OR99W. ODOT Region 2 led a multi-disciplined team of professionals from ODOT and area engineering firms, working together to complete the planning, permitting, design and construction of this major project.

The overall NDBP is being developed through multiple projects that accommodate schedule, funding and construction bonding limitations. The 2009 JTA (Jobs and Transportation Act), together with Federal and local matching funds provide most of the $232M for the current Phase 1 construction. This initial construction phase provides a two-lane highway on a new alignment between OR99W south of Dundee and OR219 northeast of Newberg. Future phases of the project will continue the Bypass south to Dayton and north to Rex Hill, and will include expansion to a divided four-lane roadway between these points.

The Yamhill County Parkway Committee, who has been active in advocating for the project for over 25 years, provided guidance for visual elements that led to a regional "Corridor Theme" that includes an open form for bridge structures, a "meandering river" concrete relief stamped into the bridge railing, and an ornamental "rolling hills" design for protective screening where required.

ODOT and their geotechnical subconsultant GRI, completed a field exploration program that identified two surface layers of unconsolidated silt and alluvium material. A cyclic testing program was a key factor in better evaluating the seismic performance of the Willamette Silt soils. GRI completed a LiDAR and field based geologic review to help evaluate landslide hazards along the project alignment. This review disclosed a series of large landslides along the alignment and the Willamette River and additional historic landslides on both sides of the Chehalem Creek. These landslides necessitated construction of two large tieback and secant pile retaining walls beneath the bypass bridge that crosses the creek.

Highway structures include ten bridges, two retaining walls and various sign structures. Three bridges originally planned through south Newberg were combined into a single half mile long, 16-span structure to eliminate settlement concerns from large embankments. A 3500-foot long noise wall along the east embankment and extending almost 2000 feet onto the east end of the bridge, incorporated 28 unique architectural formliner patterns depicting hills and trees. The bridge design team was challenged to repurpose surplus PCPS Bulb-T girders that the Agency had available from another project that was halted. Bridge designers were able to accommodate the use of all 112 beams on the project.

Phase 1 is being built under several contracts. Initial construction began in 2013, which included property acquisition, relocation, and demolition, and embankment and culvert construction. In 2014, Hamilton Construction began building the west portion of the Bypass near Dundee and in 2015, Wildish Standard Paving was awarded the contract for the Newberg portion at the east end of the Bypass, and K & E Excavating has been contracted to build surface street improvements in Newberg.

2A BRIDGE DESIGN AND CONSTRUCTION

Design and Construction of the SR 520 West Approach Bridge - North

Greg Knutson • *HDR Engineering Inc.*

The SR 520 Bridge Replacement and HOV Program is a $4.56 billion project designed to enhance safety and mobility by replacing the aging floating bridge and keep the region moving with vital transit and roadway improvements between Seattle and the Eastside. 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. This presentation will introduce the audience to this portion of the project and some of the unique and specialized features incorporated into the design of this bridge. It will also provide an overview of the bridge construction and present some of the challenges faced, and solutions implemented, during construction.

Replacing the Aging US 52 Mississippi River Bridge

Greg Hasbrouck • *Parsons*
Faith Duncan • *Illinois DOT*

The US 52 bridge over the Mississippi River in Savanna, Illinois was originally constructed in 1932. It provides a crucial transportation link for the region, connecting Savanna, Illinois to Sabula, Iowa with the nearest alternate Mississippi River crossing located almost 20 miles to the south in Fulton, Illinois. Over the years, a number of repairs have been made to the bridge and it is now rapidly approaching the end of its useful life and is in need of replacement. The proposed replacement consists of 12 spans totaling 2454 ft. from a causeway in the middle of the Upper Mississippi River Wildlife and Fish Refuge in the Mississippi River on the Iowa side to the high bluffs of the Mississippi Palisades in Illinois. A 546 ft. main span steel tied-arch over the navigation channel flanked by steel girder approach spans has been designed by Parsons Corporation in coordination with the Illinois DOT with construction expected to be complete by December 2017. Challenging aspects of the project include minimizing environmental impacts, designing around varying geotechnical conditions and a relatively deep river pool, and coordinating with various agencies including a railroad line. The large water depth and varying rock elevations across the river led to the desire to alleviate issues with the construction of deep cofferdams in favor of large diameter drilled shafts with the first use of waterline footings by the Illinois DOT providing substantial savings to the project. The influence of the structure depth on the vertical profile along with constructability and maintenance concerns led to the selection of a main span steel tied-arch with floating deck system. The steel tied-arch design incorporates redundancy design criteria and seeks to simplify details and provide a durable structure, including galvanizing members, such that it is easy to inspect and maintain into the future.

A New Signature Bridge for the City of Los Angeles - The Sixth Street Viaduct

Michael H. Jones, S.E. • *HNTB Corporation*
Michael Van Duyn, S.E. • *HNTB Corporation*
Rui Lu, S.E. • *HNTB Corporation*
Semyon Treyger, S.E. • *HNTB Corporation*

The City of Los Angles is replacing its iconic Sixth Street Bridge. Constructed with alkali silica reactive aggregate, a phenomenon unknown at the time of the original bridge construction, this aggregate led to the progressive and irreversible deterioration of the original concrete. One of America's most famous and recognizable bridges, the Sixth Street Viaduct has been used to represent Los Angeles in countless movies, music videos and TV commercials. To choose a worthy successor and provide the City with a truly signature bridge that would also meet current seismic standards, the City of Los Angeles held an international design competition in 2012 to select a design concept to meet these lofty goals. Out of the international design competition came the design concept now under construction - a series of 10 graceful continuous unbraced concrete network tied arches beginning from the City's new Arts District at the west end and terminating in the Boyle Heights District at the east end. This bridge form recalls former City Engineer Merrill Butler's historic structure that the viaduct will replace, as well as complimenting the other adjacent arch bridges crossing the Los Angeles River and constructed during the same period. The new viaduct is simultaneously elegant, efficient and cost effective while its seismic performance exceeds current standards. The new viaduct's 10 continuous concrete network tied arches alternate with 9 shorter "jump spans" spanning over the structures signature Y-Bents. The total length of the viaduct, abutment to abutment is 3058′, which includes two box girder spans at the west end. Superstructure deck framing is identical at both the tied arch and jump spans, consisting of an 8¼" thick concrete deck supported on post-tensioned concrete floor beams orientated transversely. The floor beams are supported by continuously post-tensioned longitudinal cast-in-place concrete edge girders that also serve as the ties for the arches and Y-Bents. The edge girders will have a shallow depth of about 3′-0" at arch spans. At jump spans, the depth of the edge girder is 6′-6" with the transition occurring at the end of each arch span. Transverse floor beams will have a nominal spacing of 9′-0" and a maximum depth of 5′-3" for approximately the middle third of the span and then taper to meet the depth of the edge girders. In addition to its unique geometry, the viaduct delivers several innovations to bridge engineering, including the first known use of seismic isolation backed-up with a traditional ductile frame. This seismic framing concept led to a new performance level and design concept implemented at the patented Triple-PendulumTM bearings used to seismically isolate the structure. Although common in Europe, the post-tensioning couplers used at the continuous edge girder ties are rarely used in the United States. The viaduct also takes advantage of the higher yield strength of grade 80 reinforcement, thought to be a first in seismically active California. These framing concepts provided the opportunity to construct the entire 3058′ long viaduct continuously with expansion joints located only at abutments, which enhanced both the service and seismic response of the bridge. The project is being delivered by the innovative CMGC delivery method, first for the City of Los Angeles.

2B BRIDGE DESIGN AND CONSTRUCTION

Accelerated Bridge Construction Projects in California-I-10 Tex Wash Replacement

Paul C. Chung • *California Department of Transportation*
Jason Fang • *California Department of Transportation*

This paper presents and discusses an Acceleration Bridge Construction (ABC) showcase project in California, the I-10 Tex Wash Bridge Replacement, that was delivered from initiation to completion in a record of time of 67 days. On July 19, 2015, a heavy storm event occurred in southern California and a 1,000-year flood generated by 6.7 inches of rain gushed off the Chuckwalla Mountains located in Riverside County on the California and Arizona border. The massive torrent gushed off the mountains and swept away the Tex Wash embankment and foundation, thus collapsing the Tex Wash Bridge that carried the eastbound traffic of Interstate freeway 10, located about 50 miles west of Blythe. Following emergency evaluation, decision was made to replace the existing collapsed 4-spans bridge, with following objectives: 1. Replace and reopen the bridge within a short time- 60 days 2. No collapse will happen in a future 1,000-year flood event 3. The new bridge need to accommodate future extensions from the bridge abutments to allow quick road reopening in a future washout of embankments on both ends of the bridges 4. Seismic performance of the connection between the precast bent cap and columns is equal/better to/than of the cast-in-place structure. In order to achieve these objectives, wash channel bank was realigned upstream and the abutments were re-located to mitigate and prevent future flood washouts. The structure design used an accelerated bridge construction structure type that used prestressed precast adjacent rectangular box girder superstructure supported on precast bents, abutment, and wingwalls at both ends. In order to accommodate possible extension on both ends of the bridge, both abutments were design to behave as bents/piers, and special seismic design and details were employed for the connection between the 4′ diameter CIDH pile and abutment and pier stems. These special details allowed the bridge to remain standing following a major seismic event when the bridge abutments are serving as bents in the future bridge extension configuration. Throughout the design and construction phases of the project, close partnership with federal and state agencies, internal team members, contractors, and external stakeholders took place to ensure the expedited successful delivery of the project. As a result, the structure design team only took two weeks to complete the design and delivered the plans and specifications, and the bridge construction took less than 60 calendar days, allow the bridge to be reopen to the traveling public on September 23, 2015, less than 67 days from the day of the bridge collapse.

A Signature Bridge on the Fast Track

Christopher Vanek • *WSP (Parsons Brinckerhoff)*
Adrian Moon • *WSP (Parsons Brinckerhoff)*

Signature bridges are inherently complex and unique to their specific application and require detailed consideration into construction techniques. The inherent high cost of the non-traditional designs tends to significantly increase the cost of the project, sometimes rendering it unfeasible. During the development of a Signature Bridge project for the Veterans Memorial Bridge in Volusia County, Fl. the application of Accelerated Bridge Construction technologies were seen as essential to delivering the project. The proposed bridge is composed of a pure concrete open spandrel arch bridge with a main span through-deck arch over the Halifax River. This paper will describe the engineering design process beginning with conceptualization that satisfies the owner's specific objectives and ending with the structural elements and erection techniques that minimizes cost and construction duration.

Practical Implementation of Stability Bracing Strength and Stiffness Guidelines for Steel I-Girder Bridges

Domenic Coletti • *Michael Baker International*
Michael Grubb •*M.A. Grubb & Associates, LLC*

Traditionally, cross-frames for straight steel I-girder bridges have been designed with consideration of little more than wind loads and individual member slenderness criteria. While this practice has usually resulted in acceptable designs, the lack of quantification of design loads has been disconcerting to some engineers, and some have questioned if this practice is sufficient. Recent research has advanced the state of the art in bridge engineering, particularly in the area of cross-frame design. NCHRP Report 725 provides key insights and practical guidance for the analysis of straight steel I-girder bridges with moderately to significantly skewed supports and specifically in the area of calculation of cross-frames forces; this work recommends the use of refined structural analysis methods for these bridges, which directly calculate the forces in individual cross-frame members. Meanwhile research by Yura and Helwig has produced guidelines for assessing the minimum strength and stiffness requirements for bracing members; these guidelines are provided in Appendix 6 of the AISC Specification for Structural Steel Buildings. The guidelines also provide a means to calculate minimum strength and stiffness requirements for cross-frames of straight steel I-girder bridges with little or no skew, where simplified line-girder analysis methods, which do not produce any assessment of cross-frame member forces, are commonly used. However, specific guidance is lacking with regard to the practical implementation of these guidelines within the context of composite steel I-girder bridge design performed under the provisions of the AASHTO LRFD Bridge Design Specifications. This paper recommends a proposed approach for the practical implementation of Yura and Helwig's guidelines for steel I-girder bridges. The paper also recommends appropriate load factors and load combinations for use with these guidelines, and discusses recommendations for their implementation in negative-moment regions of multiple-span continuous steel I-girder bridges. Lastly, the paper reviews the implementation of these recommendations on a design project recently completed for the North Carolina Department of Transportation, and reviews design recommendations recently published by the Pennsylvania Department of Transportation related to the use of these guidelines.

2C BRIDGE DURABILITY AND MATERIALS

Historic Perspective on Galvanic Anode Use for Corrosion Protection of Bridges

Eilseo Conciatori • *Vector Corrosion Technologies, Inc.*

Galvanic anodes were originally primarily used to only protect the still sound chloride contaminated concrete area adjacent to and surrounding patch repairs. The purpose being to prevent accelerated corrosion around patch repairs due to the incipient anode or more commonly referred to as the "Halo Effect". To accomplish this objective, small rectangular or cylindrical shaped discrete galvanic anodes were placed within and near the perimeter edges of patches. This approach only provided "localized" repairs and corrosion protection to already damaged concrete areas, but did not address future damage that occurs in sound concrete areas with high chloride concentrations and where corrosion cells have already occurred, but not yet resulted in concrete damage. This presentation will address how during the last decade galvanic anode size, shape, type and use has evolved to provide more extensive and global protection to large or entire areas of chloride contaminated reinforced concrete bridge structural members and elements. Actual project case histories will be presented to demonstrate the evolution in the usage of galvanic anodes for protecting reinforced concrete bridges from corrosion related damage.

Silane Concrete Water Repellents- An Innovative Solution That Stands the Test of Time

Tim Woolery • *Advanced Chemical Technologies, Inc.*

Silane water repellents are the first defense in bridge rehabilitation and preservation. Water is the enemy! Freeze thaw damage and Chloride damage can be prevented by using silane water repellents. Silanes are proven effective study after study, year after year. Silanes are an inexpensive tool that could be used more effectively across the country to prevent freeze thaw damage, chloride damage and rebar corrosion. This presentation covers how silanes work, surface preparation, application, test results on the longevity and performance of silanes and cost information. Attendees will learn the advantages of starting a silane program and the significant benefits achieved.

Method of Improving Concrete Durability in Bridges and Structures

Philip Rhodes • *Hycrete Inc.*

Concrete degradation is primarily caused by water, water borne chlorides, sulfates and carbon dioxide. Recently a new admixture that produces rubber like pore blockers has been proven to dramatically extend the structural and cosmetic life of concrete exposed to rain, tidal waters, cold temperatures, sulfate rich soils and high levels of air borne chlorides. This paper will explore the causes of concrete degradation and share independent test data from the Army Corps of Engineers, Universities and DOTs on extending the life cycle of concrete by utilizing this new admixture

2D FOUNDATION DESIGN AND CONSTRUCTION

Drilled Shaft Quality through Thermal Integrity Profiling

James M. Schmidt, P.E., P.Eng., D.GE. • *Terracon Consultants, Inc.*

Drilled shafts are commonly used to support large concentrated foundation loads. With their significant size, drilled shafts can be cumbersome and expensive to load test. To avoid the large cost associated with load testing, many engineers and owners choose perform integrity testing of drilled shafts. Integrity testing is performed to verify that the shaft has been constructed as specified. The most common method for evaluating integrity is through the use of Cross-hole Sonic Logging (CSL). However, CSL testing has drawbacks. CSL testing is performed between tubes attached to the shaft reinforcing steel cage. One limitation is that CSL testing can only measure shaft integrity within the reinforcing cage. From a performance perspective, the concrete outside the reinforcing cage is critical since it provides the soil structure interaction through skin friction. The concrete outside the reinforcing cage also provides protection from corrosive environmental effects. Thermal Integrity Testing is an emerging testing methodology that measures temperatures with respect to depth within the drilled shaft. It has been introduced in the past several years and is progressing from demonstration projects into more conventional use. Thermal Integrity Testing can evaluate the presence of anomalies inside as well as outside the reinforcing cage. Using temperatures, the amount of concrete cover beyond the reinforcing cage can be calculated leading to the development of a complete model of the drilled shaft with respect to depth. This presentation will examine several examples of real shafts and include a brief primer on the theory and testing methodology which will allow the audience to evaluate the condition of the example shafts. The presentation will summarize the analysis for each shaft and point out defects and bulges that were detected through Thermal Integrity Testing. Finally, it will compare Thermal Integrity Testing results with CSL results.

Innovative Large Shaft Repair for Abraham Lincoln Cable-Stayed Bridge

Claudio Osses • *COWI*
John Brestin • *COWI*

The Abraham Lincoln Bridge is a six lane, 2106ft long, 3-tower cable-stayed bridge completed in 2015. It carries northbound Interstate 65 across the Ohio River, connecting Louisville, Kentucky to Jeffersonville, Indiana. The bridge was designed by COWI (formerly Buckland & Taylor) and constructed by Walsh Construction under a design-build contract for the Kentucky Transportation Cabinet (KYTC). Each of the bridge towers is supported by a single line of four 12'-0" diameter drilled shafts. During the construction of one of the shafts supporting Tower 3, Shaft 3R-2, a major construction issue occurred related to the placement of the concrete. The O-rings in the tremie system failed and caused the aggregate, cement and water to segregate thereby compromising the quality of concrete in the lower half of the shaft. Concrete cores were extracted from Shaft 3R-2 and tested in compression, revealing an average break strength of 1.7ksi, much lower than the 5ksi specified by the design. Shaft 3R-2 was rejected and the designers sought a solution. The selected solution consisted of coring a 7'-6" diameter hole into the deficient shaft, constructing within that hole a new shaft composed of a new reinforcement cage and a massive built-up steel plate girder with shear studs. The new 7'-6" shaft built at the center of the deficient shaft 3R-2 was designed to act as a composite section, with the steel girder providing a large percentage of the required stiffness and strength of the shaft. This solution was adopted despite the perceived risks of execution. There were several construction concerns about the execution of the repair: (1) doubts were raised that a 7'-6" diameter x 120 foot long coring operation could meet the inclination tolerances required; (2) concrete may not flow well with the steel girder in the middle of the shaft; (3) steel girder shear studs could get caught with the reinforcement cage; (4) presence of water at the bottom of the excavation could compromise the quality of the concrete. The Designer and Contractor worked together to mitigate the risks by developing a special coring plan; adding deviators and holes to the steel girder; using a modified concrete mix and pour scheme; and adding a Thermal Integrity Profiling Test (TIP) to supplement the results from the Cross-Hole Sonic Logging (CSL) Testing. The Shaft 3R-2 repair was completed successfully by the Contractor. The repair was accepted after the CSL and TIP Test results proved that the quality of the concrete was satisfactory. The structural capacity of the repair shaft 3R-2 also proved to be adequate as it was able to withstand the maximum design loading condition, which occurred during construction (the unbalanced superstructure cantilever erection stage). The Designer and Contractor team successfully managed to provide an innovative and effective solution for the repair of Shaft 3R-2 allowing the project to move forward meeting all the project requirements to the satisfaction of KYTC.

Fairview Ave. Bridge - Slip Sliding Away: Challenges in Foundation Design with Flow Loads and Plastic Hinging

Ellen Brenden, P.E., S.E. • *HNTB Corporation*
Kiva Lints, P.E., S.E. • *HNTB Corporation*

One of the keys to a successful bridge design is, of course, a solid foundation. But sometimes, achieving a design for a solid foundation in less than solid soil conditions can turn a routine bridge design into a challenging project requiring additional analysis and innovation to obtain an effective, constructible and cost effective solution. This was the case for the Seattle Department of Transportation Fairview Avenue North Bridge Replacement located north of downtown Seattle along Lake Union. Designing the foundations for this bridge was complicated by a multitude of challenging conditions. Located over an edge of Lake Union, and bounded by a historic vibration sensitive bio-tech research facility on the land side and high-voltage power lines on the water side, the site of this bridge presented variable and seismically unstable soil conditions as well as other constructability challenges for the designer. The soils in the shallows of the lake, where the piers are located, were deposited by both glacial and sedimentary action, including interspersed layers of soft or liquefiable layers with more competent soils. The bowl-shaped topography at the site, combined with a historic slide plane, potential slip planes and large nearby fill areas, raised the possibility of not only liquefaction, but a flow of the upper soil layers into the lake basin during a seismic event as well as the possibility of full blown landslide. Deep foundations were the only solution to address these challenges, but arriving at a foundation design that will be both reliable during the design seismic event and economical took innovative design approaches that went beyond the scope of the written codes. The depth, size and resulting cost of the foundations affected the bridge layout, pushed the design team to minimize the number of piers, and resulted in a decision to allow a full closure of the bridge during construction rather than staged construction, in order to minimize the number of shafts in each pier and reduce cost. However, the design challenges were not limited to the foundation layout. Modeling the foundations for the seismic analysis, with liquefiable soils, varying soils as well as variable depths to the soils at each pier and shaft location, required complex modeling to create reasonable foundation and soil springs for the response spectrum analysis and the pushover models. Running the pushover models with varying support stiffnesses and soft supports that did not always produce full plastic hinging, required in-depth consideration of hinging behavior and ductility requirements. In addition, combining the capacity protection and overstrength moments with the moments produced by flow loads required research into and interpretation of code requirements for a load case that went beyond the scope of the written codes. Solving these challenges required cooperative problem solving amongst the design team and the client review team with the end result being a design that is constructible, economical, and durable.

3A BRIDGE REHABILITATION

I - 40 Willow Creek Bridge No. 5 - Unique Bridge Deck Replacement Solution

Christopher Labye • *AECOM*
Ben C. Ansley • *AECOM*

This bridge rehabilitation project highlights an unusual solution to a fast-track project with severely limited access constraints to replace a deteriorating concrete deck on a bridge that had pier columns that could not accommodate unbalanced dead loads moments generated from a phased deck removal. Interstate 40 (I-40) is a major east-west truck route through northern Arizona. The I-40 Willow Creek Bridge No. 5 (constructed in the late 1960's) required a deck replacement due to its deteriorating conditions in a highly corrosive environment (deicing salts at over 4500 feet) as well as high truck traffic volumes. The existing bridge is a 5-span continuous steel girder structure (approximately 576 feet long) with a cast-in-place concrete deck over Willow Creek wash. Additionally, the bridge required numerous girder repairs, replacement of the existing abutment rocker bearings and abutment backwall replacement. Cross-over traffic control for this deck replacement was not allowed because it would have resulted in a detour of over 7 miles of opposing traffic on westbound I-40 through relatively difficult terrain and horizontal curves. Such a long cross-over would have resulted in a long-term traffic control condition that brought up safety concerns for the travelling public. There were additional construction/time restraints as well. The entire construction needed to be completed within a 6 month timeframe (mid-April to mid-October) between the winter months. In this area of Arizona, it is difficult to clear snow off the roadways with snow plows while temporary concrete barriers (TCBs) are in place. Additionally, there was a desire to limit environmental impacts to the stream. During the design process, the existing single-column piers (some over 60 feet in height) were determined to not have sufficient capacity to accommodate phased deck removal/construction while all the dead and live loads were shifted to one side of the bridge. To limit environmental impacts to the stream, a unique solution was developed to remove and replace the deck in a "checkerboard" fashion along with the use of TCBs as counterweights. This allowed for all construction activities to be completed from the top of the bridge. During the first phase of construction, TCBs were placed in negative moment regions on the existing bridge deck while the deck was removed in positive moment regions up to points of contraflexure, followed by the new deck pour. After the deck was cured, the TCBs were shifted to the new deck in positive moment regions and the negative moment portions of the deck were removed and re-poured. This process was then repeated for the second phase of construction. The project successfully employed this process during both phases of construction and utilized temporary concrete barriers to maintain traffic on the bridge with as little as 3-inches of clearance between the temporary concrete barrier and the longitudinal construction joint along the interior girder.

Reviving a Piece of History - Healdsburg Avenue Bridge over the Russian River

Mark Weaver • *Cornerstone Structural Engineering Group*

The Healdsburg Avenue Bridge over the Russian River project consisted of the rehabilitation and seismic retrofit of a historic two span steel Parker Truss bridge in Sonoma County, California. Constructed in 1921, the bridge is listed on the National Register of Historic Places and holds a special place in the hearts and minds of the local community. After being in service for nearly a century, the existing bridge was plagued with several structural and functional issues and complete replacement was initially considered. Even when presented with options to repurpose the bridge as a pedestrian/bicycle bridge alongside a brand new modern concrete bridge through the public outreach process, it became apparent that the local community greatly desired to rehabilitate the bridge in place as a vehicular bridge,. The City and design team heard the public's concerns and proceeded down the path to rehabilitate and seismically retrofit the bridge in place. The rehabilitation and retrofit not only had to address basic structural and functional concerns, but also needed to include special design features to allow for restoration of historic elements of the bridge while strengthening and seismically retrofitting truss members, maintaining pedestrian and bicycle access that is critical to the local economy, and improving public health and safety both during and after the project. Supplementary considerations included the addition of new municipal utilities designed to remain in operation after major seismic events and establishing a long term maintenance plan for preservation of the completed project. Technical issues continued to arise throughout construction, including accounting for as-built conditions that were not documented on the five as-built plan sheets from 1920, and addressing newly discovered damage after removal of the bridge deck. Through a collaborative effort with project stakeholders including local community members, the California Department of Transportation (Caltrans), the Federal Highway Administration (FHWA) and the State Historic Preservation Office (SHPO), the City of Healdsburg and their design team successfully delivered the desired rehabilitation on schedule and within budget. In recognition of this success, the project was recently awarded an Honor Award at the American Council of Engineering Companies (ACEC) California 2017 Engineering Excellence Awards ceremony in San Francisco.

Substructure Repairs on the Susitna River Bridge in Remote Alaska

Jared Levings, P.E., Alaska DOT&PF

The Susitna River on the Denali Highway is approximately 56 miles east of the Denali National Park and Reserve between Cantwell and Paxson. This 1950 era one-lane bridge is about 1000 feet long and is comprised of a timber deck with several steel girder spans, a 165 foot truss span, and is supported on a steel substructure. Ever since construction, the truss rocker bearings have been migrating away from the pier following the roadway centerline. A secondary support system was installed in 2012 to catch the truss in the event that the bearings shifted off of the pier. The 2013 routine inspection identified fractured welds and distortion in the support elements with nearly a two-foot lateral displacement when compared with original construction. Two repairs to address the substructure damage will be examined, an initial repair to reestablish bearing implemented by Alaska's Maintenance and Operations and a pier extension installed by a Contractor. Challenges associated with bowed truss members, contractor-required bridge crane operating loads, pile alignment and fit up tolerances, and a closed welded support structure will be discussed. In addition, discussion on the project's successfulness, lessons learned, and a look to the future will be provided.

3B BRIDGE SEISMIC DESIGN

A New Type of EDD for the Seismic Retrofit of the Golden Gate Bridge Main Suspension Spans

Ted Bush • *HDR Engineering, Inc.*
Kuang Lim • *HDR Engineering, Inc.*
Ewa Bauer-Furbush • *Golden Gate Bridge, Highway & Transportation District*
John Eberle • *Golden Gate Bridge, Highway & Transportation District*

This presentation provides an overview of a new type of energy dissipation device (EDD) that will be implemented for the seismic retrofit 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 design, testing, and nonlinear time history analysis implementation of the abrasive friction EDDs. The $1.5 million abrasive friction EDD testing program was conducted in two phases and at two different testing laboratories. Phase I consisted of 0.4-scale prototype design/testing of the abrasive friction component of the EDD (pairing of materials, material wear, frictional thermal effects, etc.) at the University at Buffalo's SUNY facility using axial sinusoidal and time history displacement input at a maximum velocity of 40 in/sec. Phase II used the conclusions drawn from Phase I and consisted of full-scale prototype design/testing of a complete EDD specimen at the University of California, San Diego Caltrans SRMD facility using axial sinusoidal and 3D time history displacement input at a maximum velocity of 70 in/sec. The successful testing program results have been used to implement EDD frictional contact modeling in the global retrofit ADINA computer model and final seismic retrofit design and detailing of the bridge (including EDDs and supporting connections). Useful information is presented for the seismic retrofit analysis and design of a long span steel suspension bridge using displacement based nonlinear time history modeling. A general overview of the suspension span retrofit is provided with specific details regarding the new abrasive friction type of EDD and parallel computer modeling based on the full scale testing results.

Seismic Design Challenges of West Mission Bay Drive Bridge Replacement

Kumar Ghosh, Senior Bridge Engineer • *T.Y. Lin International*

The City of San Diego is undertaking the replacement and widening of the existing West Mission Bay Drive Bridge over the San Diego River. West Mission Bay Drive links the Sports Arena area and San Diego Bay to the south with Mission Bay Park and SeaWorld San Diego to the north. The bridge is currently operating at 60% above capacity and projections show that by 2035 the bridge will be operating at 100% above capacity. In the event of a major earthquake, the seismic analysis indicated that the existing bridge could collapse due to liquefaction and subsequent shear failure of the supporting timber piles. The proposed bridge replacement will reduce traffic congestion, enhance seismic safety, and significantly reduce operations and maintenance costs. Due to construction staging requirements, the new bridge has been designed as two separate segments, each accommodating three lanes of traffic. Various structure alternatives were evaluated during the feasibility, environmental documentation, and type selection phases of this project. A cast-in-place concrete haunched box girder has been selected as the preferred structure type. The overall proportions of this preferred bridge type were optimized in the Type Selection Alternatives Analysis, which evaluated engineering, environmental, and economic considerations. One of the primary design challenges for the replacement bridge involves the upper 70 feet of loose- to medium-dense sand that is highly susceptible to liquefaction. Under this layer of loose soil is a 40-foot layer of dense sand on top of formational materials. The bridge is also located in close proximity to the active Rose Canyon fault zone. This requires the pier piles to be designed for lateral seismic demands and the abutment piles for lateral spreading loads. The bridge foundation design is optimized to satisfy the California Department of Transportation (Caltrans) Seismic Design Criteria under both liquefied and non-liquefied soil conditions, which are very different. For the non-liquefied condition, avoiding short column requirements and the associated high seismic shear demands are both critical. For the liquefied condition, the substructures are effectively tall, and P-Delta, displacement ductility, and maximum drift are critical. As part of the Foundation Optimization Study, Type 1 and Type 2 shafts were studied with fixed and pinned column boundary conditions. A Type 2 shaft with a column-shaft pinned connection has been selected as the preferred foundation. The column-shaft pin is located below the thalweg and long-term scour depth to minimize degradation of the column pin. Also, due to the possibility of caving soils, it is recommended that permanent casings (10-foot diameter at piers and 6-foot diameter at abutments) be installed at the top of the formational material, with CIDH piles extending approximately 80 feet below the casing. Verification of the end bearing and friction capacity of the piles will be obtained using an O-cell load test in a sacrificial test pile. The existing bridge will also be monitored during installation of the new piles to mitigate subsidence risks. Construction is anticipated to commence in late 2017 and be completed in 2020.

Boeing Access Road Bridge Seismic Retrofit and Rehabilitation

Kevin Kim • *Jacobs Engineering Inc.*
Hana D'Acci • *Jacobs Engineering Inc.*

The Boeing Access Road Bridge over BNSF and UPRR was built in 1944 and widened in 1966, providing an important connection between I-5 and East Marginal Way with 40,000 ADT. The bridge is comprised of two spans of reinforced concrete girders and three spans of steel girders over the railroads, for a total 337 feet long and 73 feet wide. The City of Tukwila initially considered replacing this aging structure with another consultant but retained Jacobs Engineering to re-evaluate for rehabilitation and seismic retrofit concepts, which resulted in a savings of more than $20M in project cost. The Jacobs team performed a seismic analysis and load rating of the existing bridge and determined that the bridge did not meet the current collapse prevention criteria for a 1000-year return period earthquake. The following retrofits are to be implemented to meet the current seismic performance criteria and upgrade the bridge load carrying capacity: 1. Ground improvements to mitigate for liquefaction and lateral spreading with compaction grouting. 2. Foundation retrofit with adding 2' dia. drilled shafts onto the existing pile foundation. 3. Column Steel Jacketing at intermediate piers to increase ductility and shear capacity. 4. Concrete hinge bearings replacement at Pier 4 by removing deteriorated hinge pedestal bearings and constructing new concrete seats with elastomeric bearings. 5. Girder seat extensions to provide adequate seat length for the steel rocker bearings. 6. Longitudinal seismic restrainers over transverse expansion joint to prevent unseating of girders. 7. Concrete girder strengthening with CFRP to increase shear and moment capacities. 8. Steel girder repair for corrosion and deterioration. 9. Replacement of transverse and longitudinal bridge joints with new expansion joints. 10. Concrete crack and spall repairs of girders and columns. 11. Bridge deck repair/rehabilitation and overlay with modified concrete. In addition, the project will add a new 10-ft wide sidewalk along the south side of the bridge with steel brackets cantilevered off the exterior girders to accommodate the City's future non-motorized route.

Design Strategy to Minimize Seismic Residual Displacements and Damage in a new ABC Bridge Bent

Marc Eberhard • *Professor, University of Washington*
Travis Thonstad • *National Institute of Standards and Technology*
John Stanton • *University of Washington*
David Sanders • *University of Nevada Reno*
Islam Mantawy • *University of Nevada Reno*

A new bridge bent system has been developed to reduce on-site construction time, minimize residual displacements even after a large earthquake, and reduce seismic damage in comparison with conventional cast-in-place construction. Precast, rocking connections used in the system have been tested successfully under quasi-static conditions and found to perform exceptionally well, re-centering with essentially no concrete damage or residual drift after being loaded cyclically to drift ratios of up to 10%. The seismic performance of the new rocking column system was evaluated with shaking table tests of a quarter-scale, two-span bridge. The maximum displacements of the bents were similar to those expected for a conventional bridge through the Design Level event (PGA=0.75g). Damage to the column concrete was negligible; the columns would not need any repair after being subjected to the Design Level motion. Residual drift ratios never exceeded 0.2% up to the 221% Design Level motion (PGA = 1.66g). The only structural damage to the bridge was the eventual fracture of the column's longitudinal reinforcement and bulging of the column's confining tubes placed at the ends of the columns, both of which occurred at drift ratios of approximately 6%. Results from the subassembly and shaking table tests were used to develop a design methodology that is based on an idealization of the rocking response of the bridge columns. The methodology aligns with the displacement-based procedure outlined in the AASHTO Guide Specifications for LRFD Seismic Bridge Design (2015). The modifications to this procedure necessary to align with the objectives of the new system are straightforward and could be implemented within current design practice. A modeling strategy for the pre-tensioned bent system is also proposed and key aspects of this approach are validated against the subassembly and shaking table test results.

ABC Low Damage Seismic Technologies: From Theory to Experimental Validation and Real Life Application

Mustafa Mashal, Ph.D., P.E., CPEng, IntPE(NZ) • *Idaho State University*
Alessandro Palermo, Ph.D. • *University of Canterbury*

There are many examples of Accelerated Bridge Construction (ABC) in low seismic regions. However, applications of ABC in moderate-to-high seismicity has been limited due to concerns about seismic performance of connections during a strong earthquake. Recent studies on ABC in seismic regions in the United States and New Zealand have proposed a variety of connections between precast elements in the substructure. Generally these connections can be classified as "emulative" and "non-emulative" cast-in-place connections. Emulative connections target a similar performance for the precast substructure as that expected of cast-in-place construction, e.g. formation of plastic hinges in the columns. The research at the University of Canterbury (UC) in New Zealand included extensive quasi-static cyclic testing of two emulative connections (grouted duct and member socket) for half-scale cantilever (hammerhead) and multi-column (bent) precast specimens. Results showed adequate performance of emulative connections, however, the extent of damage in plastic hinges as well as the residual displacement were substantial. For a real-life ABC bridge using this type of technology, extensive repair or possible replacement of the bridge can be expected following a large earthquake. Therefore, this solution can be called "ABC High Damage". Non-emulative connections include Dissipative Controlled Rocking (DCR) connections. This type of connection was originally proposed for precast buildings back in the 90s. In this type of connection, unbonded post-tensioning tendons that run inside the precast elements, are combined with energy dissipaters installed at the plastic hinging zones. The post-tensioning provides self-centering of the bridge after an earthquake while the dissipaters absorb seismic energy. For a real-life ABC bridge with this type of technology, the bridge would self-center after the earthquake with minor to cosmetic damage only. Therefore, this solution can be called "ABC Low Damage". The research at UC used DCR connections with innovative external metallic dissipaters in a half-scale ABC Low Damage bent. A series of quasi-static cyclic testing was conducted on the bent to optimize self-centering, energy absorption, cracking, and fatigue performance. Results showed excellent performance of ABC Low Damage bent with DCR connections. After repeated testing, the columns remained intact without any hairline cracking and the bent was fully re-centered with zero residual displacement. The solution developed by Mashal and Palermo at UC was implemented in the World's First DCR Bridge (Wigram-Magdala Link) in Christchurch, New Zealand. The bridge opened to traffic in July 2016. The Wigram-Magdala Link Bridge is a 3-span reinforced concrete bridge with total length of 325-ft (99 m). It incorporates precast bents with DCR connections. The detailing developed at UC was refined further for aesthetic and durability reasons. Following the Kaikoura Earthquake on November 14th 2016 in New Zealand, the bridge did not suffer any damage. This paper presents a summary of the research on ABC Low Damage at the University of Canterbury in New Zealand (2011-2016). It includes description of appropriate design, testing, detailing, construction, and analytical procedures. Furthermore, it provides a clear example of technology transfer from theory and experimental validation into a real-life ABC bridge in high seismicity.

Investigation of Macro-Defect Free Concrete for Accelerated Bridge Construction, including Robotic Construction

Katelyn Freeseman • *Iowa State University*
Brent Phares • *Iowa State University*

Accelerated Bridge Construction (ABC) has grown tremendously over the past several years, in part due to the maturation of new materials that have properties conducive to working in an ABC environment. In recent years, a major construction equipment manufacturer has developed several formulations of a so-called "Cemposit", a variation of macro-defect free concrete. This material is unlike any cement-based material currently available, and is much more closely related to various types of rubber – although with vastly different properties than rubber. These favorable properties include: high strength (comparable to Ultra-high performance concrete), rapid early strength, extremely low permeability, and the ability to be extruded on-site to fit specific project needs. The goal of this project was to assess important material characteristics and to develop conceptual uses for the material with a specific focus on accelerated/robotic bridge construction. The preliminary findings are presented, along with possible applications for the accelerated bridge construction field. This research was sponsored by the Accelerated Bridge Construction University Transportation Center (ABC-UTC).

3D BRIDGE DESIGN AND CONSTRUCTION

Design of the I-405/SR167 Flyover Bridge

Alice Fong • *Jacobs Engineering Inc.*
Anthony Gasca • *Jacobs Engineering Inc.*

The I405/SR 167 interchange is one of the most heavily congested interchanges in the Seattle area. The I-405/SR 167 Direct Connector Project will relieve congestion by improving traffic flow and improve safety. The key component of the project is to add direct access between the SR167 high occupancy (HOT) Lanes and the I-405 carpool lanes. Direct access will be provided by a 56 feet wide, 1486 feet long flyover bridge, which is comprised of 11 spans ranging from 149 feet to 174 feet long. The flyover bridge is a precast girder bridge with WSDOT WF95G girders and a cast-in-place deck. Several unique aspects of the bridge will be covered in the presentation and are discussed below. Three straddle bents were used to minimize span lengths which allowed the use of precast girders and minimized impacts to the existing roadways below the bridge. The straddle bent spans range from 69 feet to 73 feet. Post-tensioned cap beam were used due to the long straddle bent spans. Pin connections were used at the top of the straddle bent columns to minimize loads transferred to the columns. The pinned connections were designed using steel pipes filled with concrete. Soil conditions vary greatly along the length of the bridge. At the south end of the bridge, soil conditions are poor with liquefiable soils overlying relatively deep bedrock. Due to the poor soil conditions at this end of the bridge, a geofoam approach fill was used to limit settlement and improve seismic performance. At the north end of the bridge, bedrock is near the surface so MSE walls were used for the approach fill. The abutment on this is supported by spread footing on the MSE fill.

Designing Long Span Precast/Prestressed Concrete Bridge Girders for Lateral Stability

Richard Brice, Washington State Department of Transportation

Precast/prestressed girders in excess of 200 ft. in length have become viable design options. The lateral stability of these girders is a serious concern. Initial lifting and transportation to the bridge site are often governing design cases. The Washington State Department of Transportation (WSDOT) has been designing precast/prestressed concrete bridge girders for handling and transportation for over 25 years. The Precast/Prestressed Concrete Institute (PCI) recently published recommendations for lateral stability of such girders. Additionally, PCI Pacific Northwest (PCI/PNW) and local heavy haulers approached WSDOT requesting updates to stability design practices to account for their modernized hauling equipment. This presentation describes how WSDOT design practices have be updated to accommodate the new PCI recommendations as well as the practical constraints of local fabricators and heavy haulers.

Design and Construction of 2nd Street Connector

Ali Seyedmadani • *WSP (Parsons Brinckerhoff)*

Design and Construction of 2nd Street Connector The 2nd street Connector is located in Historic old Sacramento connecting the Capitol Mall Bridge to 2nd Street in Old Sacramento. This bridge is part of a larger project called I-5 Riverfront Reconnection. Due to limited right-of-way the proposed bridge had to overhang the I-5 freeway depressed section retaining walls and have a unique curved geometry and profile. The eccentric loading and unsymmetrical support system will induce torsional forces in the structure during seismic events requiring straddle bend to control seismic displacement demand. The Historic old Sacramento setting, Sacramento Railroad Museum and State Park required extensive architectural treatments to be included in the bridge design for blending it to the surrounding environment. The limited right-of-way, need to maintain access to local properties, depressed I-5 freeway with seal slab were few of the factors making the construction of this bridge challenging. The five span 291 foot Cast-in-place posttensioned concrete box girder Bridge required eight feet diameter drilled shafts with isolation casing to be constructed within limited ROW. The foundations had to be constructed through a five feet thick seal slab section of I-5. Due to high water table and being near Sacramento River it was decided to specify oscillation drilling method for drilled shaft construction. The limited ROW required construction of drilling platforms using micropile system, straddling the I-5 retaining wall and the drilling site. In addition, nine feet isolation casings were utilized to eliminate force transfer between foundation system and I-5 retaining wall and construct the joint between the drilled shaft and column cage. The piercap form work and bridge falsework system had to straddle retaining wall and be partially constructed within I-5 freeway. Due to eccentric piercap loading two piers required vertical posttensioning of the column and drilled shaft. The camber calculation required consideration for both longitudinal and transverse long term deflections. The architectural treatment of the bridge and straddle bent was a critical element making the bridge to blend with the surrounding buildings, while mitigating the appearance of a conventional bridge structure. This bridge construction required extensive coordination with local property owners, Old Sacramento Business Association. Extensive traffic control was required during the night and weekend work. The I-5 freeway had to be shifted toward the median and night time lane closures where utilized for material delivery, falsework erection and equipment staging. The bridge construction was completed within nine months and has created a new access/ front door to the Historic Old Sacramento.

4A BRIDGE DESIGN AND CONSTRUCTION

Design and Construction of the Rockingham Bridges 24N & 24S

Nicholas T. Rodda, PE, SE • *HDR Engineering Inc.*

Located in southeast Vermont in the town of Rockingham, two deck truss bridges carry Interstate 91 over the Williams River and the Green Mountain Railroad. Built c. 1961, these existing bridges are nearing the end of their useful life. In response, the Vermont Agency of Transportation (VAOT) released a Request for Proposal for a pair of replacement bridges in November of 2015. The Base Technical Concept was for a three span cast-in-place segmental box girder bridge. HDR partnered with contractor Reed & Reed to develop an Alternative Technical Concept (ATC). The ATC put forth by the Reed & Reed team was a four-span continuous, post-tensioned precast spliced girder superstructure. The two main spans each have a length of 245 feet and the overall bridge length is approximately 852 feet. Being built on the same alignment as the existing bridges will allow the existing piers to be used for temporary supports during construction. The girders used in the design are New England Bulb Tee girders, modified to have thicker webs to accommodate 4 inch diameter tendons and to be haunched at the piers. Due to limitations of the precast fabricator, the hammerhead sections at the piers were limited to 10 feet in height and a weight of approximately 180 kips. Once the girders are erected, cast-in-place closures will be cast between the girder segments and the girders will be post-tensioned together from end to end of the entire bridge. The VAOT has required that the bridge be designed for a 100 year service life. In order to provide for this service life, the clear cover over the reinforcement is increased, the deck and bridge rail reinforcement will be stainless steel, and the deck will be covered with both a waterproof membrane and a 3 inch thick asphalt overlay. Design for the girders was completed using the PGSplice component of the BridgeLink software, one of the first production uses of this software. To accommodate traffic during construction, the northbound bridge will be replaced first with the existing southbound bridge being converted to two way traffic. The northbound bridge is expected to be complete by late 2018. The southbound bridge will follow, with an expected completion of late 2019. When complete, the Rockingham Bridges 24N and 24S will be the longest spliced girder bridges in New England. This presentation will cover preliminary design constraints, the structural challenges encountered during design and the on-going challenges of constructing this unique structure.

Using Single-Column Bents with Large Eccentricities to Avoid Straddle Bents

Nicholas Murray, SE • *HNTB Corporation*
Kuan Go, SE • *HNTB Corporation*
Aamir Durrani, PE • *HNTB Corporation*

This paper presents two approaches to avoid straddle bents through the use of eccentric single-column bents, referred to as cantilever bents. For highway and light-rail structures, cantilever bents are typically employed when the eccentricity between the superstructure and column is under 8 feet, above which a straddle bent is used. This paper covers the design of cantilever bents with eccentricities up to 20 feet in zones of moderate- and high-seismicity. Straddle bents are often used when a bridge crosses a street or railroad at a large skew. Straddle bents allow the spans that cross the obstruction to be similar in length to the adjacent spans, whereas eliminating the bent altogether would require a doubling in span length. Replacing straddle bents with cantilever bents provides the benefit of reduced footprint and improved appearance, while maintaining the desired span lengths. The two examples in this paper are from recently completed projects: Honolulu Authority for Rapid Transportation (HART) in Honolulu, and the I-405 Sepulveda Widening in Los Angeles. The HART project is a 400-span viaduct that runs along the median of an at-grade highway. In one location, a left-hand turn lane needed to be accommodated at a constrained location of the highway. The I-405 project widened or reconstructed 23 bridges, and the northernmost bridge was complicated by a sensitive 96" diameter underground waterline and roadway intersection underneath the widened bridge. Both examples used cantilever bents with large eccentricities, but each example used a different approach. The first method to be discussed resists the full eccentric demand in the bent by horizontal post-tensioning (PT) in the bentcap, and vertical PT in the column, thereby providing a semi-rigid support to the superstructure. The second approach is to stiffen and strengthen the superstructure to shed loads from the "flexible" support. A parametric study will show the impacts to the superstructure and substructure designs when the stiffness of the support ranges from semi-rigid to flexible. C-Piers 277-279 of the HART project are three consecutive and identical cantilever bents with an eccentricity of 20.2 feet to the superstructure, which is simply supported segmental box girder. Post-tensioned columns and bent caps are used to provide a semi-rigid support. The level of prestressing required in the columns exceeded what could be provided by PT rods, so (9) 27-strand PT ducts are used in each column. Using strand ducts in the column provided more efficiency in terms of reducing the column size, but it increased the complexity of the construction. Sepulveda Blvd Undercrossing, aka "Bridge 23", carries I-405 over Sepulveda Blvd at a large skew, and the widened center support uses a cantilever bent with an eccentricity of 19.3 feet. The steel superstructure is integrally cast with the PT bent cap and the column is comprised of reinforced concrete. Geometric restrictions prevented the use of a straddle bent, and clear spanning the road was not preferable due to deflection compatibility of the existing bridge.

City of Santa Monica California Incline Bridge Replacement Project

Curtis Castle, PE • *City of Santa Monica*
Scott Dendall, PE • *CALTROP Corp*
Peter Smith • *T.Y. Lin International*

The $16 million Cal Incline Project replaced the existing California Incline bridge structure and roadway. The California Incline is one of only two vehicular access points into the City from the Pacific Coast Highway and is an integral part of the regional transportation system. The total project length was approximately 0.28 miles and included replacement of the old bridge, which was 750 linear feet in length, and the approaches on both ends. The upper (east side) bluffs were reinforced and secured using 1,000 soil nails ranging in length from 25 feet to 80 feet, with the longest nails being installed 100 feet high on bluff face. The 22-inch thick post-tension bridge deck sits on 96 CDIH piles each 30-inches in diameter. The Cal Incline Project provides a new bridge wider than its predecessor with a 16-foot wide pedestrian/bicycle shared path. The outer balustrade on the old bridge was considered an iconic feature of the Santa Monica coastline and the new Cal Incline pays homage to that with a similar and slightly more modern balustrade. The Cal Incline Project provides the community and region with seismically sound traffic route while also coming to the forefront of mobility by safely accommodating multiple modes of transportation. The Cal Incline Project presented several key design and construction challenges – lack of space; interruption to regional traffic flow; and a short schedule. Lack of Space: The bridge is bounded by a bluff face on the east and steep grade with existing vegetation on the west. The Pacific Coast Highway lies at the bottom of the westerly grade. To construct the bridge deck, the contractor utilized a complex system of temporary falsework consisting of concrete piling, steel columns and beams, and heavy timber. The installation of falsework required the contractor to work out over a steep grade off of the existing bridge with little buffer between their work area and PCH. Traffic Management Traffic management was key to the project's success. Prior to construction, CMS boards and notification signing was installed. Upon the start of construction, a full detour route was deployed including DMS boards which provided real-time travel times to motorists. Additionally, the City and the CM team worked with City of Los Angeles to permit the installation of detour signing within L.A. and provide LADOT traffic officers at key intersections during peak travel periods. Short Schedule: The City used a project delivery A+B format, which required the bidders to propose the construction duration as part of their bid. Each day carried a cost of $9,500, so the shorter the duration that was bid, the lower the overall bid. The low bidder provided a 365 calendar day duration, which was minimum allowed. The contractor adopted means and methods of building the project to reduce both the project cost and schedule through value engineering.

4B PEDESTRIAN BRIDGE PROJECTS

Minto Island Bicycle & Pedestrian Bridge: Design and Construction

Bob Goodrich, PE • *OBEC Consulting Engineers*
Jim Bollman, PE • *OBEC Consulting Engineers*

Renewal of the City of Salem, Oregon's downtown waterfront has been ongoing for decades, and the new Peter Courtney Minto Island Bicycle & Pedestrian Bridge is the final key element in the City's vision to connect their waterfront parks, which are spread over miles on opposite sides of the Willamette River. The Minto Island Bridge connects Salem's downtown Riverfront Park to an extensive natural park on Minto Island, a riparian tract separated from the downtown waterfront by Willamette Slough. The crossing is located at the narrowest section of the slough. Water levels in the slough vary by more than 25 feet between low flow and the 100-year flood, and hydraulic, environmental, permitting, construction, and aesthetic factors motivated a clear span over the slough. The bridge ties into the paths in Riverfront

Park and connects to an existing embankment on Minto Island. The structural configuration is a five-span bridge, with a main tied-arch span of 304.5 feet and thin CIP post-tensioned haunched slab approach spans – three at 50 feet on the island, and one at 35 feet in Riverfront Park. The tied-arch span consists of two 30-inch-diameter by one-inch wall round tube ribs, each bent to a hyperbola and tilted away from the deck at 25-degrees from vertical. Precast deck panels are suspended by 1.5-inch-diameter rods, arranged in such a way that when projected onto the rib plane, they are radial to a point 490 feet above the midspan of the springline. The hyperbolic shape follows the thrust line of the in-plane suspender load components axial and perpendicular to the ribs. The precast panels are hung from the suspenders in a parabolic vertical curve profile and contain two 15-strand bundles of 0.6-inch-diameter PT strand, one bundle for each rib tension tie. The suspenders lie out-of-plane to the rib curvature, which serves to balance the gravity moment of the inclined ribs about their ends. The balance of out-of-plane forces provided by the suspender force component perpendicular to the plane of curvature on one side of the plane, and the gravity component on the opposite side, imparts out-of-plane braced behavior to the ribs in the absence of the traditional concept of bracing. The panels also function as stay-in-place forms for a CIP topping slab. Full-length deck post-tensioning through the approach spans and the topping slab of the arch span provides capacity to the approaches and precludes live load tension at the arch span panel joints. CIP haunched panels connect the precast panels to the arch piers in the arch span. The completed arch span deck, while very slender, is resistant to pedestrian-induced resonant vibrations. In addition to the unique design, notable elements of the construction engineering and inspection included high-resolution scanning of the rib fabrication and placement, and a non-linear stepwise analysis of a coordinated sequence of panel placements, arch tie stressing, and falsework support releases integrated with the contractor's falsework system.

Iconic Scioto River Pedestrian Bridge

Dan Fitzwilliam • *T.Y. Lin International*

The City of Dublin, Ohio, is undertaking a development program to establish a cohesive community vision for all aspects of future development, including: character, walkability, and pedestrian experience; connectivity and access; and supporting infrastructure. The Dublin Historic District is situated on the west bank of the Scioto River. To provide a vital transportation link and integrate new developments on the east bank of the Scioto River with planned and existing developments in the Historic District, a new pedestrian bridge across the river was commissioned. Because of its key location in the heart of the city, the bridge has to have iconic characteristics defining its place. T.Y. Lin International and the architects at Endres Studio worked with the City of Dublin to develop a bridge type that would fit the criteria of the site and serve as a regional destination along the scenic Scioto River corridor. The bridge is a suspension bridge with a reverse "S"-shaped alignment. A single plane of stays on the inside of curve switches from the left edge to the right edge of the deck. The dominant and most architectural feature of the bridge is the 160-foot-high pylon, which has a teardrop-shaped hole where the footbridge threads the eye of the needle. A triangular steel box girder warps along the length of the bridge to accommodate varying stay configuration, and creates a dynamic visual experience as the pedestrian moves from one side of the river to the other. The bridge deck has direct vertical or longitudinal connection to the pylon and is designed to be floating through the opening. T.Y. Lin International closely analyzed the dynamic behavior of the cable-supported pedestrian bridge during the bridge design phase. In-depth studies of the vibrational characteristics of the bridge for wind and live load vibrations led to innovative design features. At the east landing, a unique abutment configuration allows for vertical and horizontal moment and shear fixity while allowing free axial movement. This presentation explores the unique and challenging design and construction aspects of this footbridge, which is currently under construction. Completion of the new Scioto River Pedestrian Bridge is scheduled for late 2018.

Construction Methods for Rural Pedestrian Suspension Bridges

Nathan Bloss • *CH2M*
Matthew Bowser • *WSP*

This paper discusses procedures and practices implemented by Bridging the Gap Africa during the construction of Kakenya's Crossing, a short span pedestrian suspension bridge located in rural Kenya. It is the second suspension bridge constructed utilizing a design developed by WSP in coordination with Bridging the Gap Africa (the first bridge was completed in 2016). The design focuses on simplicity and constructability while aiming to create a more versatile alternative to a suspended bridge with minimal increase in cost. Suspended bridges primarily differ from suspension bridges in the camber of their deck. A suspended design uses raised towers or elevated terrain at the abutments to achieve adequate freeboard and compensate for its 'hanging' deck; whereas a suspension design invokes negative camber in its deck by varying the length of suspenders supported by its main cable. Bridging the Gap Africa has enabled the construction of 61 life-saving bridges throughout rural Kenya. Each bridge provides vital access to markets, schools, and health care facilities over rivers that are often difficult to cross. However, site constraints can limit the implementation of suspended bridges; low-lying areas are especially challenging due to their additional freeboard requirements. The suspension bridge design used at Kakenya's Crossing leverages many of the benefits of a suspended bridge while remaining adaptable to sites with flatter topography. This paper discusses the advantages and disadvantages of suspended and suspension bridges and provides insight into design characteristics that make Kakenya's 98 foot (30 meter) suspension bridge particularly well-suited to its environment. Construction of the bridge was performed by the local community with oversight from Bridging the Gap Africa. Specific approaches were implemented during construction to cope with the unique challenges presented by the remote location. The sustainability of the bridge through its design life was a key design consideration, since maintenance and inspection may not occur with the same regularity practiced in the United States. Sustainable materials were selected for major structural components, and weathering protection was applied to promote durability and sustainability. Quality control methods were used to limit uncertainties in local materials used for structural components. Bridging the Gap Africa partnered with the University of Buffalo to investigate the effects of 'dirty' aggregates on concrete compressive strength. Suspended and suspension bridges are an effective and economical engineering solution used to address rural infrastructure needs in developing countries worldwide. The construction of these bridges presents unique challenges that must be addressed through the planning, design, and construction phases of the project. By creating a sustainable short-span suspension bridge design and safe construction practices for its implementation, Bridging the Gap Africa hopes to enable local residents to build hundreds of footbridges in communities throughout Kenya.

4C BRIDGE TECHNOLOGY AND SOLUTION

Recent Innovations in WSDOT Bridge Design and Construction

Bijan Khaleghi • *Washington State DOT*

This presentation focuses on three recent innovations used on WSDOT bridges. The first project focuses on use of superelastic materials consisting of shape memory alloy (SMA) along with engineered cementitious concrete (ECC) in plastic hinging regions of the columns of the SR 99 South Access Connection Bridge for improved seismic resiliency. The connections were tested at the University of Nevada Reno before the system was implemented on-site by WSDOT. The second project focuses on use of Concrete-filled steel tubes (CFSTs) in bridges as piers, piles or shafts. Prior research indicates that CFSTs have flexural strength and stiffness capacities that exceed structural steel and reinforced concrete components with similar diameters and steel amounts. A research program was undertaken at the University of Washington to investigate the shear capacity of large-scale tubes. A range of design parameters were studied including aspect ratio, diameter-to-thickness ratio, concrete compressive strength, tube type, tail length and interface condition. The third project focuses on use of ultra-high performance concrete (UHPC) for connection of newly developed wide flange precast deck bulb tee girders. UHPC with its superior properties of higher compressive strength and modulus, and very low permeability, can provide improvements over conventionally build deck girder bridges with grouted key connections in terms of structural efficiency, durability and cost-effectiveness. UHPC mixes using local materials were developed at the Washington State University and connections were tested at the University of Washington. In all cases, the use of prefabricated bridge components along with innovative materials and designs offer an improved alternative to conventional bridges.

Bridge Lighting Efficiencies for Bridges Spanning Navigable Water

Rowan Plaxton • *Sealite USA, LLC, Western North America*
Lee Walker • *Sealite USA, LLC*

The U.S. Coast Guard, Bridge Administration Division, mandates minimum lighting requirements for bridges spanning navigable water. The challenges for engineers, constructors, installers, and bridge owners include planning for the initial lighting installation, budgeting for material investment, prolonged or ongoing light maintenance, and operational monitoring. Many of the issues associated with bridge lighting can be partially or entirely mitigated when incorporated during new [bridge] build, or when a renovation or repair of an existing structure is planned. Problem Statement: Installation of navigation lighting on bridges spanning navigable water requires considerable work to bring electricity to a site. Routing and trenching of utility power to the bridge requires considerable manpower, equipment, and time. Utility hook-up and ongoing utility costs can usurp operating budgets. Maintenance, from a simple bulb replacement to extensive wiring repairs, is costly and, potentially, dangerous. In more rural areas, maintenance may require specific vehicular support and highly specialized and skilled labor. Monitoring may require extensive travel and man hours. Approach: By using a completely autonomous solar battery and LED lighting system, the requirement for mains power is eliminated, thereby minimizing associated installation and operational costs. Utilization of highly efficient, solar, LED technology, with appropriate color, range, beam width and sectoring can be economically satisfy the U.S. Coast Guard requirements for marine navigation. Remote monitoring of operational status may also be achieved for further economies of labor and costs. Results: The use of self-contained, low cost, highly efficient, eco-friendly LED solar bridge lighting systems are an ideal lighting solutions as they reduce installation costs, eliminate expensive and ongoing utility costs, and reduce expensive maintenance monitoring costs thus reducing the overall expenditures for bridge lighting over navigable water and allowing for utilization of funds elsewhere within a bridge renovation or new-construction budget.

Using Bridge 3D Models after the Design Process

Alexander Mabrich • *Bentley Systems*

Bridge engineers have been creating 3D models for bridges for many years. These models were mostly used for analytical purposes as advanced calculations, and finite element methodology required a 3D model. Over time, these 3D models have evolved from a model of sticks and nodes to full realistic solid models. Nevertheless, there was always a gap between analytical models needed for design calculations and physical ones used for a real representation of the bridge structure. Nowadays, innovative software solutions are "bridging" the gap between these two models by creating a physical model of the structure with all details necessary for an accurate representation and geolocation of the structure in the real world, and using the same model for transferring to analytical software, perform the design calculations and send the information back to the physical model. Nowadays, bridge engineers are facing the challenge of how to make the vast information generated by their structure useful for professionals further down the line in the lifecycle of the bridge. Contractors and inspectors require that a 3D model is provided after the design process, but at the same time recognizing that they do not use or have the calculation or specialized CADD software used to develop the model. Moreover, they also require the ability to add extra information to the same 3D model that pertains to their particular activities and store that information in the same one. The purpose of this paper is to present the technology available to generate, manage, and enrich the bridge 3D model with intelligent information and how it is used for construction and inspection in the areas of clearance verification, geometry and quantity reports, scheduling and construction planning.

4D BRIDGE MANAGEMENT

Structural Monitoring of Floor-Beam/Stiffener Connections on the Benicia Martinez Bridge.

Maged Armanuse • *CalTrans, Office of Structural Materials*
Miguel Hernandez-Garcia • *CalTrans, Office of Structural Materials*

The Benicia-Martinez Bridge is a 1.9-km steel truss bridge crossing the Carquinez Strait and linking Benicia, CA with Martinez, CA. The bridge was built in 1962 and had undergone several widening and seismic retrofit upgrade projects. Presence of fatigue cracks on the floor beam stiffener welds of the stringer-to-floor beam connections have been reported since 1982. Fatigue cracks have been regularly inspected and monitored, and hole drilling has been consistently used to arrest crack propagation. A permanent repair strategy has been proposed to modify the floor-beam/stringer connections in order to minimize and/or stop fatigue crack propagation in the floor beam webs. Prior to proceeding with permanent repairs, a trial phase will be carried out to assess the expected performance of the repair. In order to characterize the actual structural response of the connections, a structural monitoring system will be deployed to measure and collect vibration and strain measurement data. A structural monitoring system was installed to measure the vibration and strain response of four (4) floor-beam/stringer connections on the Benicia-Martinez Bridge under normal operating loads. The monitoring system consisted of a set of twelve (12) triaxial accelerometers, three (3) per connection, to measure the longitudinal, lateral, and vertical vibration response at the top flange of the floor beam, and at the welded and free edges of the upper section of the web stiffener. Measured acceleration responses were used to estimate relative displacements between the stiffeners and the top flange of the floor beam. A total of thirty-two (32) biaxial strain gauges, eight (8) sensors per connection, were deployed to measure and estimate the strain distribution on the floor-beam web along the stiffener weld on the floor-beam/stringer connections. A high-channel-count data acquisition system (96 channels) was used to simultaneously collect, record, and transmit all acceleration and strain data measured at the four monitored connections. Strain and acceleration measurements were continuously recorded during six (6) weeks and sampled at a sampling rate of 200 Hz (200 samples/second). A data-driven and statistical framework was implemented to characterize and summarize the acceleration, displacement, and strain responses measured during the field campaign at each of the monitored floor-beam/stringer connections before and after the repairs, as well as to assess the performance of the selected repair strategy. This study presents a summary of the results obtained during field investigation and monitoring of the floor-beam/stringer connections on the Benicia-Martinez Bridge.

Who Wants a Green-Certified-Platinum-Triple-Star Bridge? A Bridge Engineer's Introduction to Current Sustainability Rating Methods

Kelly Burnell • *Kleinfelder, Inc*

After a brief hiatus during the economic downturn, sustainability is again becoming a factor in project selection and execution. The question remains: How can sustainable design and construction be included in a bridge project? The emergence of sustainability rating systems for infrastructure projects can provide bridge designers, owners, and contractors a framework for targeting and quantifying sustainable elements of their projects. However, questions about the different frameworks (What do they focus on? How do they overlap? Where are they relevant?) tend to confuse the issue, clouding the problems engineers are trying to solve. Focusing on the attributes of a typical bridge project, this presentation will provide an overview of the sustainable rating systems most relevant to bridges, including Greenroads, Envision, and INVEST. It will address the focus, methods, and expected results of each framework as well as cover the overlap between them. Discussion of pilot or sample projects that included bridge work will also be included. Such topics as life-cycle cost analysis, relative energy input bridge types, deconstruction, and bridge life extension are covered as they apply to the rating systems. The combination of a good working understanding of sustainability planning frameworks and a more integrated approach will allow bridge design teams to leverage more cost-effective sustainability opportunities into any project, while providing communities and owners with the greater degree of certainty and accountability that comes from a widely used and understood rating framework.

Evaluation of Gusset Plate Connections in Steel Truss Bridge

Bo-Shiuan Wang • *COWI NA*

The I-35W Bridge cross Mississippi River in Minnesota collapsed in 2007 was, in part, attributed to the overstressed gusset plates joints. This incident triggered the necessity to evaluate the existing gusset plate connections in steel truss bridges. The stresses in gusset plate connections are complex because of the variety of load distributions from connected members and the diversity of the gusset plate geometry. In many years the design/ evaluations of gusset plate's capacity depend mostly on the Whitmore's (1952) methods and rule of thumb. This paper presents a triage evaluation for gusset plate connections and a study of gusset plate stresses correlated to connected member loads and gusset plate geometries. The triage evaluation uses principal stresses to filter gusset plates in potential danger. For those gusset plate connections flagged in the triage evaluation, a refined approach is used to calculate the stresses on the gusset plate connections. The refined approach is established by using FEM to develop a simplified modeling methodology and analyze parameters affecting gusset plate stress distributions. It is found the end chord stress is not only affected solely by the chord load but also affected by its anti-symmetric geometry, splice locations and the load from adjacent diagonal. An approach to calculate the stresses at chord end in the gusset plate is proposed. Based on better insight of stresses from chords and diagonals, stresses at critical sections of gusset plate can be easily calculated. The refined approach then calculates several relative high stresses at the critical sections of gusset plate and point out the largest Von Mises stress in the gusset plates. The triage evaluation and refined approach can be modified to fit into the load rating methodology to improve the current load rating procedure for steel truss bridge gusset plate connections.

5A BRIDGE DESIGN AND CONSTRUCTION

Spliced Precast Concrete Girder Bridges - 20 Years of Lessons Learned in Design and Construction

Gregg Reese • *Modjeski and Masters / Summit Engineering Group*

Using precast concrete for longer span and complex interchange applications is being rediscovered as a valuable design option in many locations across the United States. The presentation will feature a number innovative bridge projects constructed with Spliced Precast Girders over the last 20 years. These bridges that will be discussed are both straight and curved with medium and long spans using both Bulb Tee and U Girder cross sections. All of the projects, which are currently in service in Colorado, Texas and Florida, were designed to accommodate complex roadway geometry and site conditions and utilize both straight and curved girders. The substructure designs for many of these projects also incorporate innovative solutions that reduced construction costs and improved long term durability. A brief overview of each project and specific innovative design features of each will be discussed. All of the projects to be discussed had numerous design and construction challenges in difficult urban site conditions with multiple traffic crossings. Maintenance of rail and passenger traffic required complicated phasing and innovative solutions to accommodate large traffic openings. The construction of these projects required extensive construction engineering to resolve issues of handling, transporting and erecting large, heavy and occasionally unstable curved girders. Methods of erecting and stabilizing the girders on temporary supports during construction will be discussed. In addition the development of precast U girder standards for Florida and Pennsylvania will be discussed. The case studies that will be presented are drawn from over 30 projects the author has been involved with over a twenty year period. These projects represent numerous examples constructed under both conventional design/bid/build as well as alternate delivery systems such as design/build, contractor initiated alternate designs and value engineering. Several of these projects have won national design awards. Innovations, lessons learned and the advantages that have been realized using this type of bridge technology will be discussed as well as potential improvements, future applications, actual construction experiences and economic attractiveness of this type of bridge construction.

Sellwood Bridge Replacement Project

Eric Rau • *T.Y. Lin International*
Ian Cannon, P.E. • *Multnomah County*

This presentation provides an overview of the award-winning Sellwood Bridge Replacement Project, focusing on the design and construction of the three-span steel deck that crosses the Willamette River south of downtown Portland. These arch spans, which have a total length of 1275-ft and are composed of 5,000 tons of structural steel, are the signature feature of the bridge replacement project. T.Y. Lin International was the Prime Consultant for the final design phase and, as Engineer of Record for the steel deck arch bridge, provided engineering services throughout construction. Major sub-consultants included Cornforth Consultants for landslide mitigation and CH2M for roadway, geotechnical, bridge/structural and civil engineering. The project, which centered on replacement of a historic but deteriorated and obsolete 1925 steel truss bridge that had a National Bridge Inventory rating of 2, was administered by and is owned by Multnomah County. It was delivered under the CM/GC contracting method via a joint venture between Slayden Construction Group and Sundt Construction Company. Final design was completed in 2012, and the new structure was opened to traffic in February 2016 with substantial construction completed in January 2017. The presentation will address the final bridge configuration and key components from both a design and construction perspective including the solid-ribbed steel arches, the spandrel column layout and associated bridge articulation, the bridge deck cross-section and lane configuration, the concrete piers and Y-arm arch springing, and the drilled shaft foundations. Unique features that will be highlighted include the cofferdam construction scheme for the perched piers, the requirements for and details to make the bridge "streetcar-ready", and the "shoofly" staged construction configuration which utilized the existing truss in a translated position. A brief overview of the effects of the landslide on the west bank of the river will be provided, and site-specific design criteria related to seismic and vessel collision extreme events will be discussed. Additionally, fabrication and erection via the piece-by-piece method will be highlighted. The project was recently selected as ACEC Oregon's 2017 Project of the Year, and also received an Honor Award in ACEC's national competition for exceptional engineering achievement. Located just a few miles south of downtown, the new Sellwood Bridge is both a worthy successor to the 1925 steel truss and a sterling addition to Portland's renowned collection of bridges crossing the Willamette River.

Riverside Drive Viaduct Replacement

Y. Nien Wang • *HNTB Corporation*
Jiahwa Wang • *HNTB Corporation*
Shirley Lau • *City of Los Angeles, Bureau of Engineering*

The Riverside Drive Viaduct Replacement is located in the City of Los Angeles at the intersection of the Interstate 5 Freeway and Riverside Drive and provides a crossing of the Los Angeles River as well as railway tracks and Avenue 19. The new bridge replaced the existing bridge with a two lane, standard curve viaduct that was configured for a design speed of 30 mph and provide a barrier protected auxiliary lane for pedestrians and cyclist. The bridge improved pedestrian safety and link currently disconnected segments of the City's bicycle route and path system, and improves traffic circulation at San Fernando Road/ Riverside Drive intersection. The construction of the bridge was finished and the bridge was opened to traffic in January 2017. Los Angeles Mayor Eric Garcetti mentioned in the opening ceremony that the Riverside bridge is the City's first bridge with protected bike path and roundabout. The replacement structure was striped as a two-lane bridge, with one traffic lane in each direction as well as a painted median. The east end of the bridge terminates near a new roundabout that was used for the intersection of Riverside Drive and San Fernando Road. Sidewalk and bike path were provided on the north side of the viaduct. In consideration of the construction staging requirement, the complex vertical and horizontal alignments, and rail clearance envelope requirements, the bridge consisted of a two-span and a three-span cast-in-place post-tensioned concrete box girder structures, and slab bridge. This structure type provided superior torsion resistance and structural ductility. The box girder structures were constructed in two stages due to traffic control. A deck closure pour was provided for connecting two stage structures. A soffit closure pour between Bent 3 and Abutment 6 will was provided for structure integrity and to provide the supports for 40 in diameter water main. A new 40" diameter pipe replaced the existing 40" diameter water main carried by the existing bridge structure. To emphasize and capture the appearance of an historic river arch bridge, a non-structural, monolithic arch-shaped exterior girder with a depth varying from 12-ft to 40-ft was provided. The substructure system consisted of multi-column bents for Bents 2, 3 and 5. The reinforced concrete columns were approximately 4 ft or 8 ft in diameter and supported on pile shafts. This foundation system can resist both large vertical and lateral loads, while maintaining a small foot print to minimize interference with the existing river channel wall and other existing improvements. Reinforced concrete pier wall supported by CIDH pile footing was designed for Bent 4. The channel invert slab and the channel footing at Bent 4 were restored flush and against the proposed pier wall to provide part of the lateral support for the bridge structure under lateral loads. Seat type abutments were designed for Abutments 1 & 6.

5B BRIDGE REHABILITATION

Kotzebue Slough Bridge Substructure Repairs in Remote Alaska

Jared Levings, P.E. • *Alaska DOT&PF*

The Kotzebue Slough Bridge is located in a western Alaska native community north of the Arctic Circle. This 1980 era two-lane, three-span bridge is about 180 feet long and is comprised of a timber deck, timber beams, and a steel substructure. The 2014 underwater inspection identified a detached H-pile splice with substantial loss of bearing and a lateral displacement exceeding 10 inches. Due to seasonal barge access being limited to July through August, an underwater pile splice was implemented. Two stiffened WT strong backs and threaded rods aided in temporarily realigning the pile to allow for an underwater bolted field splice to be installed. Challenges associated with underwater work, sequencing, limited surface area, realignment forces, and access will be discussed. A short history, successful project completion, and lessons learned will also be provided.

Reconstruction Challenges of a Nationally Historic Arch Bridge in San Diego

Ebrahim AmiriHormozaki, PhD, PE • *Kleinfelder*
Nathan Johnson, PhD, PE • *Kleinfelder*

Thorough reconstruction was recently performed to address rehabilitation and retrofit needs for the historic 102-year-old Georgia Street Bridge and retaining walls. At the 2015 WBES, prior to construction, the design team provided a presentation on the design approach. This paper will focus on construction, including a review of how the complex staging, demolition, and reconstruction was implemented, and a thorough discussion of lessons learned from a design perspective. The bridge arch-ribs have three hinges with floating end spans supported on approximately 30-foot tall anchor-block abutment walls. Adjacent anchor-block retaining walls create an approximate 670-foot long grade separated traveled way below the bridge. The reconstruction replaced entire bridge superstructure and spandrel columns with identical geometry and retrofitted arch-ribs to increase shear capacity and service life. The arch-rib retrofit was performed using hydro-demolition, shear tie strengthening, and a self-consolidating concrete mix containing glass. The abutment and retaining walls were stabilized using ground anchors and soil anchors tied to new facing. The roadway below was lowered at three stages. Due to the challenges associated with partial reconstruction of an arch bridge, and strengthening/replacement of walls that support existing 100-year old buildings, the design team was heavily engaged during construction. This project illustrates how prior prediction of these challenges during the design phase could result in a rigorous and practical construction schedule that met the deadline and construction budget. The project team was successful in overcoming challenges faced during the construction of this project and the bridge reconstruction will preserve the historic resource for future generations.

WSDOT Experience Resurfacing Existing Bridge Decks with Hot-Mix Asphalt

Dick Stoddard • *Washington State Department of Transportation*

The combination of aging infrastructure and large modern HMA paving equipment creates unique engineering and construction challenges for owner's looking to maintain HMA driving surfaces on bridges. WSDOT has recently resurfaced several existing structures, including both monumental and short-span bridges. This presentation will cover construction load limits, means & methods, contracting challenges, industry feedback, engineering responsibility, contract enforcement, and lessons learned.

5C SUBSTRUCTURE ANALYSIS AND CONSTRUCTION

US 20 Pioneer Mountain – Eddyville Construction Innovation and Engineering

Jamie Viramontes • *Oregon Department of Transportation*
Derryl James • *Oregon Department of Transportation*

The US 20: PME project is Oregon's largest transportation infrastructure improvement project since Interstate five was constructed in the 1960s. The new 5.5 mile roadway bypasses a 10 mile section of US 20 constructed in 1917 which had major safety concerns along with truck mobility restrictions.

Construction began in the spring of 2005 under a design build contract, with a $140 million budget. Construction proceeded until 2010 when landslides and geotechnical issues caused construction delays where four major bridges were designed and partially constructed. The cost of the project had increased to $217 million by 2011, when ODOT negotiated an end to the design build project. In 2012, ODOT took control of design and project management with an additional $141 million to complete the project. After resuming construction in the spring of 2012 with phase 1, ODOT committed to opening the road by October of 2016. The new design installed 3,216 feet of 78 inch multi-plate pipe instead of building the four bridges at varying stages of completion. The longest multi-plate pipe was 944 feet long. The challenge was to install over 120 miles of horizontal drains, install multi-plate pipe and place 2.5 million cubic yard of embankment in a coast range that receives 100 inches of rainfall per year. The weather effectively narrows the construction window from June – September. The project was phased into four separate projects. The new alignment was opened to traffic on schedule. Construction costs are expected to be $365 million as additional work was designed and added to the west end of the project which is scheduled to be complete September of 2017. The project corridor runs through the rugged terrain of the Central Oregon Coast Mountain Range which is characterized by layers of up-thrusted ocean seabed, known as the Tyee formation. This terrain is prone to landslides and the sandstone/siltstone layers produce very poor quality aggregates. These properties, coupled with the remote location and intense rainfall, combined to create significant engineering challenges of landslide correction, earthwork balance and complex hydraulic design. Since 2005, a total of 7.9 million cubic yards of material have been moved within the jobsite. The engineering challenges required close collaboration between the highway engineer and geotechnical consultant. The geometric placement of the highway alignment, drainage design and large scale earthwork features were all driven by the need to reduce the risk of landslides. The project was designed such that all excavated material was used as common embankment or placed as landslide buttresses. The primary culverts were engineered to follow the most stable terrain and to accommodate an acceptable amount of deformation, resulting the unique design of culverts with horizontal and vertical curves. Trench drains, under drains, blanket drains, chimney drains and horizontal drains were designed to draw down ground water and ground anchors were used to stabilize landslides where constraints prevented the use of buttresses.

Applications and Implications of AASHTO for Assessment of Vessel Collision Risk and Vulnerability for New and Existing Bridges.

Michael Roberts • *HDR Inc.*

The occurrence of bridge impacts due to vessel collisions and the associated damage, inconvenience, and associated costs of bridge repairs and replacements has grown exponentially over the last 50 years as a result of increased shipping and barge traffic combined with larger vessels in our navigable waterways. Considered an extreme event where collapse of the bridge must be avoided (Life-safety), vessel collision lateral loads on new or existing bridge piers without protection measures can be relatively sizable in magnitude, ranging from 2,000 kips for barge traffic up to 25,000 kips for medium-density ship traffic and 40,000 kips and beyond for very large vessel-travelled routes. Vessel impact lateral loads are generally controlling extreme lateral loads on bridges over navigable waterway and attention to proper mitigation measures is key to minimizing risk and ensuring survivability of existing and proposed bridges. The intent of this presentation is to briefly introduce the structural design aspects related to AASHTO LRFD and the predecessor Guide Specification as a basis for understanding and determining the risks associated with the design of a new bridge, or vulnerability assessment of an existing bridge, over navigable waterways which may be subject to accidental vessel collision. Following a brief historical survey of documented vessel collisions, the presentation aims to review the current AASHTO bridge code requirements and expectations, discuss structural loading implications, and summarize the design based components necessary to properly evaluate the risk and potential for a ship or barge collision to a susceptible bridge element. Importantly, addressing some of the challenges associated with the sourcing and filtering of relevant data and reviewing approaches for how large forces can be considered in the structural analysis and design of new and existing bridge components, with a focus on soil structure interaction, push over, or time history approaches. The presentation/paper will explore and discuss how both conventional and technologically advanced means and methods are utilized to build the most representative site specific vessel traffic conditions: Approaches which are leveraged to assess the risk and produce performance-based structural solutions for mitigating and optimizing potential for vessel collision and damage. Using a series of case studies for new and existing major bridges, the presentation will explore the application of vessel collision results and wrap up with discussion of approaches taken by HDR for new and existing bridge projects around the United States where vessel collision was a major factor.

Repair of Large Diameter Non-Redundant Drilled Shaft

Alan Marchman • *ASCE*
Kuan Go • *HNTB, Corporation*

The West O'ahu/Farrington Highway Design-Build Project is the first of its kind in the State of Hawaii. The $480 million transit project is the first segment of a phased State and Federally funded program to add an elevated light transit commuter line, proving a vital link for commuters into and out of downtown Honolulu. This first segment of elevated Guideway structure spans 7 miles and is constructed in a mix of rural and urban environments. The elevated structure consists of a mix of span-by-span and balanced cantilever segmental post-tensioned superstructure supported on single column piers founded on oversized drilled shafts, designed for seismic loading. Construction of this segment of the project is nearly complete at the time of writing of this paper. Difficulty during construction at one drilled shaft site, Pier 235, resulted in Cross-hole Sonic Logging (CSL) testing results that were below the acceptance threshold for the 7.21-ft. diameter shaft. Upon further investigation via coring and concrete break testing, it was determined there were several sizeable locations of poorly consolidated concrete that would result in significant underperformance of the shaft and would necessitate repair. The Design-Build team analyzed several alternatives to repair the shaft including: • High-Pressure Grouting • Installing micro-piles within the shaft footprint, including in-field testing of bond strength • Abandonment of shaft and installation sister shafts with a pile cap. However due to the large loads acting on the shaft, combined with a small constructible zone within the median of Farrington Highway, another alternative was required. Ultimately, large-diameter coring of central 4' diameter area the shaft followed with concrete replacement was determined to provide the safest, most-economical repair method. The repair involved dealing with many complexities ranging from assuring worker safety to intrusion of groundwater. The completed repair ultimately led to increased performance of the shaft compared to the original design. This presentation will discuss some of the merits and pitfalls of other repair alternatives as well as provide an in-depth look at the chosen repair alternative and how the final results were achieved to provide a competent repair allowing work on the Guideway to continue.

5D BRIDGE TECHNOLOGY AND SOLUTION

Incorporating Innovative Materials into a Seattle, WA Bridge to Improve Seismic Resilience

Jedediah Bingle PE, SE • *Washington State Department of Transportation*

The current seismic design philosophy for non-essential bridges is to maintain life safety by requiring no collapse. The expected condition of a bridge structure following a moderate to severe earthquake may require repair from minor spall patching up to complete bridge replacement. The repair or replacement bridges with resulting damage can be costly and timely. There are also economic impacts when a bridge is out of service. A closed bridge not only restricts the public from crossing, but also prohibits any essential emergency response, necessary post-earthquake. The innovative materials of shape memory alloy (SMA) and engineered cementitious composite (ECC) have been developed and tested to eliminate the need for bridge closure, while incorporating an energy dissipating mechanism. SMA and ECC replace longitudinal steel reinforcement and conventional concrete in the column plastic hinge regions. SMA is a metal alloy that has a super elastic behavior. The material extends beyond the yield point, similar to conventional steel reinforcement, but returns to its original undeformed shape after a seismic event, unlike steel. To replace the brittle concrete which cracks and spalls with significant hinge rotations, ECC is used in the plastic hinge region. ECC is a fiber reinforced concrete-like composite that has a considerable tensile capacity, to maintain the material's integrity during excessive hinge rotations. These materials have been incorporated into a bridge in Seattle, Washington, the first of its kind in the world. This bridge is in the vicinity of the south end of the tunnel replacing the Alaskan Way Viaduct Bridge along State Route 99. Lessons have been learned during the procurement of these innovative materials, as well as during the construction activities to incorporate them in the field.

High Load Multirotational Bearing for the Tilikum Crossing

Ronald J. Watson • *R. J. Watson, Inc.*

The new Tilikum Crossing in Portland, Oregon is a signature bridge which enhances the downtown skyline and provides a vital link from the east side of Portland to downtown. Designed by MacDonald Architects and engineered by T. Y. Lin International, the cable stayed bridge is the first major bridge in the USA that was designed to allow access to transit vehicles, cyclists and pedestrians but not cars. The overall length is 1720 feet with a main span of 780 feet, a height of 180 feet and vertical clearance of 77.5 feet. The owner, Tri-Met selected Kiewit Corporation to build the Willamette River Crossing which is the first major bridge to be built in Portland since 1973. A bridge of this magnitude requires bearing devices with a proven track record on cable supported bridges. After a thorough review of available systems the engineers involved selected disk bearings for this signature span. Disk bearings have an outstanding performance history on all types of bridge all over the world for more than 40 years. This presentation will cover the development of disk bearings and focus on the stringent loading conditions of the Tilikum Crossing. There will also be a discussion on the testing requirements with an overview of similar case histories on other cable supported bridges.

Fiber Reinforced Polymer Decks and Challenging Micropile Installation for Pedestrian Bridges in Difficult Terrain JP Loomis, CH2M

Michael Mayberry • *NDOT*

The bridges carrying the SR-28 Shared Use Path follow a steep, rocky slope wedged between Lake Tahoe and Nevada's busy State Route 28. The steep slope, environmental restrictions, and a requirement that construction not impede high volumes of tourist traffic on SR-28 effectively prohibited conventional foundation construction, leading the design team to search for a structure type that could be built quickly with very light and nimble equipment. The solution is based on a very lightweight fiber-reinforced polymer (FRP) bridge deck. This very light-weight superstructure cut both vertical dead load and lateral seismic demands on the foundations to a fraction of the forces that would result from a conventional superstructure. This allowed 1300 linear feet of pedestrian bridges to be supported on small-diameter micropiles without conventional concrete piers. This presentation describes the design challenges that lead to this innovative structure, and outlines the design details that allows construction that barely touches the existing terrain. It will also discuss the use of the Construction Management at Risk (also known as Construction Manager/General Contractor) method of project delivery.

6A BRIDGE DESIGN AND CONSTRUCTION

Helpful Hints for Designing in Alaska

Leslie Daugherty, PE, SE • *Alaska DOT&PF*

The AASHTO Bridge Design Specifications standardize many aspects of bridge design across the country, but preferred structure types and design details tend to evolve in individual states. State DOTs have varying levels of standard drawings, specifications, and design resources to document these preferences. The Alaska Department of Transportation and Public Facilities (DOT&PF) Bridge Design Section has very few standard drawings for bridges, so this presentation will explain common details and why they're used, as well as clarifying why standard drawings for them wouldn't be practical. Additionally, valid design assumptions elsewhere might not always be true in Alaska. For example, sometimes spread footings aren't cheaper than deep foundations and precast construction may not be faster than cast-in-place. Through case studies and lessons learned, this presentation will give a bridge designer who has limited experience in Alaska insight into producing consistent, practical, and economical designs.

Issues in Cofferdam Design and Construction

Michael Garlich • *Collins Engineers, Inc.*

Construction and repairs of in-water substructures frequently require installation of cofferdams. While the contractor normally provides the design, there is limited design guidance to assure that there is consistency between designs. Issues such as allowable pile and bracing member stresses (or load factors), seal design and uplift resistance, wale unbraced length, local scour, and stage construction often depend on the designer's judgment. In addition, the design parameters are dependent upon, and must reflect, the specific installation and removal practices. Cofferdam design is dependent on the contractor's risk assessment of river and construction conditions. Where cofferdams are founded on rock, or abut existing foundations, methods of sealing are critical to good performance. Methods such as compressible seals, trenching, and double walls are some possible solutions, each having its own applications. For repair situations, three-sided, or limpit, cofferdams may be utilized. In sloping ground, such as a pier near the riverbank, unequal lateral forces must be addressed. Unbraced length of wales is highly dependent upon installation conditions and may change at differing stages of construction. Particularly where wales must be sequentially lowered as excavation progresses, wales may be temporarily blocked which may not provide restraint. Establishing design stresses in wales, struts, and sheet piling must also account for the use of used materials that may have damage, miscellaneous welds, or lack mill tests to support material properties. Cofferdam design may also need to accommodate vertical loads from caisson drilling equipment. This requires the wales and sheeting to support vertical loads and for the sheet piling to be designed as a bearing pile subject to bending moments. In this case, the sheet piling can be designed using standard bearing piles design methods modified to account for the planer effect of the sheet pile walls. In many cases, concrete seals are required to resist hydraulic uplift pressures and control water ingress. Uplift may be restrained by the seal self-weight or in combination with pile, sheet pile, or drilled shaft losing uplift resistance. Both concrete/steel bond stresses and mechanical connection are used to transfer loads to the seal concrete. Seal structural design must provide sufficient shear and flexural strength and is normally plain concrete. Concrete seal design should consider the constraints on tremie placement as well as mass concrete behavior.

The Design of the Chena River Bridge at University Ave

Jesse Escamilla III • *Alaska DOT&PF*

ADOT&PF is using the CMGC procurement method it its design of a corridor rehabilitation of University Avenue in Fairbanks, AK. Although a consultant team is selected for the CMGC project, the ADOT&PF Bridge Section maintains design of the bridge portion of the project. As part of the project the existing University Ave will be replaced with a 3-span 310ft long by 86ft wide pre-stressed decked bulb tee bridge. The project has presented many challenges including geometric constraints, replacement of the bridge on the busy University Avenue corridor, and the short northern Alaska construction season (April – September). This presentation will go into detail of the design phase of the project and how during the CMGC process the current design was selected. The project has morphed from multi season phased construction bridge replacement to a single season full closure replacement while maintaining pedestrian access across the river. Although a multitude of superstructure types and non-closure options were investigated the CMGC process has validated that the typical ADOT&PF bridge consisting of decked bulb tee girders on concrete filled pipe pile foundations remains the most cost effective and timely bridge type for the State of Alaska.

6B BRIDGE DURABILITY AND MATERIALS

Case Studies for 125-Year Service Life Utilizing High Strength Low Chromium Reinforcing Bars

Neal Berke • *Tourney Consulting Group, LLC*
Rajani Vijayakumar • *Tourney Consulting Group, LLC*
Justin Thomson • *Tourney Consulting Group, LLC*

The required service life for many large bridges and other infrastructure projects is becoming a minimum of 100 to 125 years, often without needing major repairs. For reinforced concrete, the approach is typically to use a low permeability concrete to reduce chloride ingress and improve the overall durability of the concrete to the environment. In severe deicing salt exposures or marine environments, enhancing the corrosion resistance of the reinforcing bars by utilizing corrosion resistant alloys, coatings, or corrosion inhibitors is required. This paper shows how one can use corrosion data from the literature combined with modeling of chloride ingress to predict service life performance and life-cycle costs of several commercially available reinforcing bars. New long-term data showing performance in cracked concretes, with and without the addition of calcium nitrite corrosion inhibitor is presented. These data show that performance equivalent to 2304 SS can be obtained with the combination of A1035 steel and calcium nitrite. The analyses show that ASTM A1035 low chromium, reinforcing bars can meet the long-term service requirements at a competitive cost to other corrosion resistant reinforcing bars.

Accelerating Construction and Improving Service-Life using UHPC in Bridge Infrastructure Projects

Gregory Nault, PE, SE • *LafargeHolcim - Ductal*

Ultra-high performance concrete (UHPC) is one of the major breakthroughs in concrete technology in the last two centuries. It is a fiber-reinforced, cementitious material that offers exceptional mechanical and durability performance, including compressive strengths exceeding 22,000 psi and excellent resistance against environmental degradation. For this reason, UHPC is being considered for a wide variety of structural applications, particularly in bridge infrastructure projects. The Federal Highway Administration (FHWA) has taken significant interest in this material as part of their Every Day Counts program to promote accelerated bridge construction (ABC) through the use of prefabricated bridge elements (PBE) connected together onsite using field-cast UHPC to form simple, strong, durable connections for improved long-term performance. Over 180 bridges have been constructed throughout North America utilizing this innovative technology, a handful of which are located in Western states such as California, Oregon, Washington, and Idaho. This presentation will discuss what UHPC is, what characteristics it exhibits, the advantages to using it, and the various structural applications that have proven successful over the years. It will include a brief overview of the projects completed to date in these Western states.

Specifying Lightweight Concrete for Bridges

Reid Castrodale • *Expanded Shale Clay and Slate Institute*

In the last few years, most bridge engineers have become more familiar with the properties and benefits of lightweight concrete, which has important applications in reducing the weight of structures, both for new structures (especially for accelerated bridge construction (ABC) projects with large precast elements) and for superstructure replacement or rehabilitation projects where existing substructure elements are being reused. Lightweight concrete can be especially useful for projects in seismic regions where foundation design loads can be reduced. However, some engineers still have questions regarding how to specify lightweight concrete for bridge projects. This presentation will focus on helping engineers to understand lightweight concrete so they can use and specify it to successfully employ its benefits in projects. After a brief introduction to lightweight aggregate and lightweight concrete, practical details of lightweight aggregate and the production of lightweight concrete will be discussed as they relate to specifying lightweight concrete for bridges and transportation structures. Issues that need to be considered when specifying the density of lightweight concrete and other material properties will be discussed, including modifications to testing methods. Construction related topics that should be addressed in specifications are also presented. Finally, several examples of specifications for bridge projects using lightweight concrete will be given.

6C LIGHT RAIL BRIDGE PROJECTS

Design-Build of the First Ten Miles of Honolulu Rail Transit Project

Kuan Go • *HNTB Corporation*
Alan Marchman, P.E. • *HNTB Corporation*

Project Overview Currently the largest budget design-build project in Hawaii, the $8.6 billion Honolulu Rail Transit Project (a.k.a. the Honolulu High-Capacity Transit Corridor Project) is an urban rail rapid transit system under construction in Honolulu County, Oahu, Hawaii. The mostly elevated 20-mile system features design elements from both heavy rail systems and light metros, with a commuter rail-like design incorporated into trains and suburban stations. The design/build project includes installing elevated precast segmental guideway sections, drilled shaft foundations, direct fixed and ballasted rail, systems interface and integration, utility relocation, maintenance-of-traffic, intelligent transportation systems and pavement restoration. HNTB led design for the first 10 miles of elevated guideway and the maintenance and train storage facility, connecting West O'ahu with downtown Honolulu and Ala Moana Center. Structural Solutions: To deliver structural solutions that meet the challenges of the project's congested, urban environment, the guideway was designed to be constructed from above using precast concrete box girder segments. This method allowed the contractor to precast the superstructure segments at a precast yard while constructing the substructure elements on site. The project consists of 438 total spans, 430 of which are made of precast concrete and range in length from 68 to 151 ft. The remaining eight spans are cast-in-place concrete, constructed using the balanced cantilever method, with span lengths from 204 to 342 ft. The substructure consists of typical single columns with flared capitals, supported by single drilled shafts. Some locations require offset piers or straddle bents to clear roadway or intersection obstructions. There are also hammerhead piers at station locations which were designed to accommodate station platforms, design and constructed by different entities, under different design-bid-build Contracts by the owner. At each station location, artistic diagrams are added to columns using formliners. The typical guideway superstructure consists of a precast concrete trapezoidal box girder section that is 30 ft. wide and 7 ft. 2 in. deep. The cast-in-place, Balanced Cantilever sections are also 30 ft. wide but vary in depth from 17 ft. at the piers to 7 ft. 2 in. at the ends. The 11-ft length of the precast concrete segments utilizes the maximum legal transporting limits on the roads, minimizing the amount of precast concrete segments. The precast concrete segments are made of high-strength concrete that allowed for quick stripping of the forms so that production was maximized. The precast concrete spans are longitudinally post-tensioned, with tendons anchored in the expansion joint segments and all deviate in the span at about the third points of the span. The cast-in-place spans are longitudinally post-tensioned using internal tendons. The top slab is transversely post-tensioned using tendons. Project Status: The first 10-miles of Aerial Guideway construction is 95%, and is scheduled to be substantially completed in May 2017.

Light Rail Transit Bridges - Crenshaw/LAX Transit Corridor Design-Build

Aamir Durrani • *AISC*
Hoda Emami • *ASCE*
Kevin Acosta • *ASCE*
Murali Hariharan • *ASCE*

There are six LRT bridges part of the $2 Billion Crenshaw/LAX Transit Corridor Design-Build Project. The I-405 UP is a 4-span post-tensioned concrete haunched box-girder bridge over I-405 freeway with main span more than 315 feet long and total length of 788'-3". The substructure consists of 9'-0" diameter round column at Bents 2 and 3 founded on 132" diameter Type II CIDH pile; and 7'-0" diameter round column at Bent 4 founded on 108" diameter Type II CIDH pile. Isolation casings at Columns 2 and 3 are provided to accommodate future widening of I-405 roadway. The main-span of this signature and yet complex bridge presented a unique set of challenges from prestressing design while meeting long-term deflection criteria per Metro Rail Design. It also required special track-structure interaction analysis to confirm passenger comfort was not be compromised. The abutments included isolation features, from isolation casings for the abutment piles to a soldier pile supported air-gap at the abutment footing to protect the 100-year old brick sewer that runs parallel to the bridge from seismic loading. The Green Line Underpass provides the connection of the new Crenshaw/LAX Line to the existing Green Line. It is a CIP concrete post-tensioned box girder, similar to the typical Caltrans highway bridges, although it has been adapted to accommodate the Metro. The alignments of the lines being perpendicular to each other lead to a Y-shaped structure which in turn was broken down into three frames for seismic purposes. The interaction of multiple frames and changes in orientation of these required careful tuning of the foundations to make sure they were compatible under seismic conditions. Foundation placement was complicated due to the number of utilities in the ground. The Type II column-pile shaft foundations used seismic isolation to assist in the tuning where required. The Aviation/Century UP is 9-span post-tensioned concrete box girder bridge that supports a station in addition to the light rail tracks. This signature structure forms the gateway to Los Angeles International Airport and in future may contain direct link to the airport. The reinforced concrete platform girders presented unique set of challenges to get them to work. The bridge supported seismic loads from platform. The 111th Street UP is a 140 feet long single-span concrete through girder bridge that carries two light rail tracks. Manchester Ave UP is a two-span two-cell concrete post-tensioned bridge with total length of 284 feet. La Brea UP is 128 feet single-span concrete post-tension box girder bridge. This bridge spans a seismic fault line, and therefore, both the abutment and the embankment included special features to accommodate it.

Sound Transit Eastlink and Lynnwood Link Aerial Guideway

Joshua Schettler • *Jacobs Engineering*
Kent Ferguson • *Jacobs Engineering*

In the Greater Seattle area, Sound Transit is rapidly expanding its Regional Light Rail system to the east and to the north. The 7 mile long East Link Project runs from I-90 at the East Channel Bridge through Bellevue and out to the Overlake Transit Center next to the Microsoft Campus. The 8.5 mile long Lynnwood Link Project extends from Northgate to Lynnwood along the heavily congested I-5 corridor. The two projects have a combined 6 miles of aerial guideway structure.

The typical aerial guideway for both Eastlink and Lynnwood Link consists of precast prestressed tub girders, CIP deck and single column bents founded on a large diameter drilled shaft foundation. The preferred span configuration is simple span. Continuous span structures are used at stations, long span structures crossing I-5, I-90 and I-405 and several other locations.

The design for East Link Project is complete, project packages have been awarded, and construction has begun. The final design for Lynnwood Project extends into 2018. Start of service for both extensions are targeted for 2023.

This presentation will provide an overview of both projects and describe some of the challenges of aerial guideway layout optimization in an urban environment, cost implications of building a light rail system in the greater Seattle area, and computer modelling of these long rail structures. Sound Transit requires seismic design for two earthquake performance levels- the Operating Design Earthquake (ODE) and the Maximum Design Earthquake (MDE). During the design process Sound Transit updated its design approach for the ODE performance level and realized construction cost savings.

6D PEDESTRIAN BRIDGE PROJECTS

Quantifiable Contextuality: The Idaho Avenue Pedestrian Bridge

Hunter Ruthrauff • *T.Y. Lin International*

The discussion around context sensitive design often revolves around geometric features that were generated based on qualitative interpretation. Geometric features in this essence can be derived from capturing the genus loci, or what the ancient Roman's referred to as the "spirit" of the site. Other interpretations on form can be generated from cultural influence or themes that resonate within a city and so forth. All of these factors, while important to defining a project that is contextually sensitive, are interchangeable in the sense that interpretation is in the eye of the beholder and how their perspective defines contextual relevance. Every now and again architects and engineers work with such restrictive sites that there exists a truly better alternative that can be quantified as such. The Idaho Avenue Pedestrian Bridge located on the sea cliffs in Santa Monica, CA is such a project. This bridge ties into the historic Idaho Trail that leads to Palisades Park above the cliffs and crosses over the historic California Incline Road leading to the entrance of a secondary existing bridge that takes you over Pacific Coast Highway to the beach. Its alignment is uniquely shaped like an Archimedean spiral and transforms from a sloped ramp into a spiraling staircase. The project features an iconic set of v-piers that are doubly curved in every dimension leading to a soffit surface that is continuous as it stretches toward the ground plane. The project was shaped such that the path continuously ramps down at ten percent from the trail while traversing over the vertical clearance envelope of the California incline below. Its form is a derivative of finding the shortest distance across the road below and identifying the fewest number of stairs down once the landing was reached. Therefore its nautilus like alignment was generated to provide an efficient mode of travel but in fact reinforced and gave birth to the undeniably qualitative characteristics that make it an instant icon.

Tiger Mountain Lower High Point Steel Truss Bridge Design and Construction

Jane Li • *RHC Engineering, Inc.*
Jim Patton • *Washington State DOT*

The Lower High Point Bridge is located 1.2 miles southeast of High Point Trailhead at Tiger Mountain, near the south side of Interstate 90 Exit 20. Replacing an older timber bridge damaged in 2009 flood, the new bridge is a 200 foot long self-weathering steel truss with three continuous spans. The uniqueness of the bridge is its large span to width and height to width ratios, its remote and challenging construction access, and its complicated geotechnical conditions. Because of the innovative design, all these challenges were solved with a cost-effective construction solution. The bridge design considered aesthetic fitting in the natural environment using two tree sense columns. Due to the limited construction access, conventional construction vehicles were not able to access the bridge site, the truss elements are designed for field assembly. To save cost and use smaller helicopters to transport materials, the bridge was designed to accommodate the lifting limitations of the helicopter, by designing smaller truss segments and using field bolting. Thirty feet above the Lower High Point Creek, the bridge superstructure is a four feet and ten inches tall pony truss, with top chord of the truss also working as the top of the railing to save the cost in installing separate railings. The bridge deck is four inches thick treated timber deck. The two intermediate columns are made of curved 12 inches square steel tubes. The spread footings, column pedestals, and abutments are cast-in-place concrete. The foundations were laid outside of potential geological hazard areas. Constructability is an integral part of the design process to fit in the lift limit of a typical small helicopter. This bridge has many unique features that include: 1. Curved tall columns made of steel tubes at intermediate piers that fit in the mountain environment. 2. Innovative lateral design with designed unbalanced stiffness for lateral force distribution. Lateral design studied distributing foundation stiffness evenly to columns and abutments by adjusting the pier columns stiffness. 3. Extreme challenging construction access with the remote locations. Segmental construction is introduced to use small helicopters to lift the truss pieces. Small helicopters were selected for cost-effectiveness. The bridge structures were designed by fielding bolting of the segmental members. The installation falsework was made of remote-controlled sky wires that were secured on the trees. The bridge design also featured compatibility with the environment and sustainability, cost effectiveness, aesthetics, and effective use of materials. 1. The bridge layout was thoroughly studied for placing footing outside of potential geotechnical hazard such as bank erosion. The superstructure truss and substructure columns were built from Self-weathering steel, which has low maintenance and rustic scene fit in surrounding. Use of spread footings saved cost, and most importantly, reduced environmental impact from construction of deep foundations. 2. Material saving is achieved through using truss members as railing, through anchorage bolt yielding to reduce foundation size, and through a continuous truss structure to reduce the member demands. Standard size steel tubes are readily available as the construction materials.

Reuse of Unreinforced 1920s Railroad Piers for New Pedestrian Bridge

Lucas Miner • *PSOMAS*

Wenn Chyn, City of Los Angeles, Department of Public Works

In 1929, the Pacific Electric Railway constructed a steel girder bridge on concrete piers over the Los Angeles River. In the 1950s, the bridge was no longer needed and the superstructure was removed and recycled, leaving five large concrete bridge piers in the river. Over time, the piers became a cultural landmark for local residents and a local artist was commissioned to paint a 40' by 20' mural on the face of one remaining pier, to memorialize the "Red Car" trains that used to pass through the village. As a part of the pedestrian access plan for the Glendale Boulevard – Hyperion Avenue Viaduct Complex Improvement Project, the City of Los Angeles decided to place a new superstructure on top of the old Pacific Electric Railway Bridge piers to allow permanent pedestrian access across the river. Without as-builts, and with only a small amount of preserved bridge history, Psomas worked with the City to research the structural feasibility of this idea. Concrete corings revealed that the bridge piers and footings were unreinforced. After combing through railroad design manuals and codes from the early 1900s, and examining current university research on the seismic performance of unreinforced bridge piers, Psomas estimated design loads, design capacities, and recommended alternatives which meet current California bridge design specifications. The City of LA is currently moving forward to construct this bridge in 2018. This presentation will describe our findings and methodologies for the successful reuse of this iconic structure.

7A BRIDGE DESIGN AND CONSTRUCTION

240-Foot-Long Precast Single Span Bridge – Chief Joseph Dam Bridge Replacement Project

Jason Pang • *KPFF Consulting Engineers*

The existing two-lane 1950's built 94.2 m (309 feet) long bridge, consisting of 39.6-m (130-foot) historic timber truss and five approach spans, was deemed structurally deficient in 2011. In 2014-16 a concrete replacement was designed and constructed. The new record breaking single span bridge is comprised of five 72.6-m (238-foot) long 2.5 m (100 in.) deep post-tensioned deck-composite girders. The substructure is comprised of two concrete H-pile supported abutments. Each girder consists of three precast segments, shipped more than 370 km (230 miles) from the fabricator to site. Stirrups were pre-bent to make clearance. The girders were carried through the existing truss span erected on false work and installed, and then post-tensioned together after closure pours attaining the required strength but before deck slab being formed. High-performance concrete is used for the precast girder segments. Four tendons per girder are comprised of seventy-six 15-mm-diameter (0.6 in.) low relaxation 1862-MPa (270-ksi) strands. Challenges included environmental, geotechnical, life cycle cost, demolition and constructability.

Broadway Bridge Tied Arches - Value Engineering

Natalie McCombs • *HNTB*
Rick Ellis • *Arkansas State Bridge Engineer*

Arkansas Highway and Transportation Department has replaced the Broadway Bridge over the Arkansas River along the existing alignment in downtown Little Rock, Arkansas. It was anticipated that the bridge would be closed to traffic for 6 months to allow construction of the approach spans and to float the new arches into place. The contractor reopened the bridge to traffic in 5 months one month ahead of schedule. This presentation will discuss the design considerations of the two basket-handled 440 foot tied network arch bridges over the Arkansas River. During the design process, the designers were met with challenges to satisfy design criteria that compounded and increased costs. The initial desire to allow for installation for the River Rail Trolley required a floor system with longitudinal composite stringers and transverse non-composite floorbeams. Combined with the initial aesthetic inclination of the arch, the length and depth of non-composite floorbeams drove the height of the floor system and increased weight of structural steel. A value engineering study was performed to allow for future expansion of the River Rail Trolley, the aesthetics of an inclined arch, plate loss criteria and inspection access. The study revealed ways to save costs to the project and still satisfy the modified design criteria the owner wanted.

I-15 Capitol/Cedar Interchange Helena, MT

Dustin Hirose, HDR
Stephanie Brandenberger • *MDT Bridge Bureau*

This project involved reconstructing Interstate 15 between the Capitol Interchange and Cedar Street Interchange in Helena, MT. The focal point of the project was the replacement of a pair of bridges that span over the Montana Rail Link (MRL) rail yard. The new bridges are about 800ft long and span 14 railroad tracks. Impacts to the rail yard and to interstate traffic between the two closely spaced interchanges were key criteria during the project design phase. The project was delivered through a unique approach to identify risks early and develop strategies to mitigate those risks. The project included a comprehensive Bridge TS&L Study which served to identify and manage risk early. Both MDT and the MRL rail engineers were at the table throughout the Bridge TS&L phase. Having a detailed understanding of rail yard operations was imperative to determine plausible methods for constructing the bridge. Additionally, by including the railroad in the bridge type selection process, the team was able to obtain buy-in early during project development, avoid iterations, and ultimately accelerate project delivery. Maintenance of traffic during construction was important due to traffic volumes and weaving movements on the interstate between the closely spaced interchanges. There were no acceptable detour routes or options for shifting the alignment due to R/W constraints. Interstate traffic would need to be shifted onto one side of the interstate while reconstructing the opposite side. This required single lane, head-to-head traffic during construction on the narrow existing bridge. It was important that one of the new bridges could be built in a single construction season to avoid head to head traffic and crossovers during the winter. A detailed evaluation of construction scheduling was completed during the design phase in order determine needed track work windows to include in the construction contract and to verify that one bridge could be built in each season ahead of the winter shutdown. The bridge foundations were a critical item considering cost and risk during construction. It was questionable whether or not driven steel piling would obtain adequate lateral and uplift capacity in a relatively shallow dense cobble/boulder matrix. However, compared to other foundation types, a pile foundation would significantly reduce construction schedule, reduce the needed track work windows, and reduce project cost. MDT, HDR, and geotechnical engineers worked to develop a pile test program early in the design phase to determine that the required axial, lateral, and uplift capacity could be obtained at shallow depths. Ultimately, the test program resulted in a reduction of construction schedule of approximately 1 month and a cost savings of about $3M. Two superstructure types (concrete and steel) were designed to increase competitive bidding. The winning bid came in lower than estimated and was recognized by NSBA for low cost/high value. This unique approach to project development helped to reduce risk during construction, reduce schedule, and ultimately reduce cost. The first phase of the project construction has been completed a full month ahead of schedule. The final phase will be complete in 2017.

7B ACCELERATED BRIDGE CONSTRUCTION

Accelerated Bridge Construction: National Perspective and ABC-UTC Activities

Atorod Azizinamini • *Florida International University*

Most U.S. roadways were designed to carry much less traffic than the current levels of service, and many bridges are approaching their 50-year design life. Construction activities related to bridge replacement and rehabilitation are contributors to traffic jams, reduced mobility, and safety hazards. ABC has the capability to reduce both the frequency and duration of work zone disruptions. Shorter and less frequent work zone disruptions, in turn, reduce societal losses from construction-related traffic accidents, traffic delays, tailpipe emissions, and poor system reliability. With the daunting reality of bridges across the country continually being added to the nation's inventory of substandard bridges, business as usual is not an option. A paradigm shift is needed to stop building bridges the way they were built when the Interstate was first constructed over half a century ago. Keeping traffic flowing while upgrading substandard bridges must become the primary goal of each bridge upgrade project. ABC has the potential to reduce both the frequency and duration of work zone disruptions. Shorter and less frequent work zone disruptions, in turn, reduce societal losses from construction-related traffic accidents, traffic delays, tailpipe emissions, and poor system reliability. ABC is a delivery solution method of building and repairing bridges with the capability to reduce the interruption to traffic and increase safety. This presentation will provide overview of status of ABC at national level and work being conducted at ABC-UTC (www.abc-utc.fiu.edu) to advance the cause of ABC.

Seismic Behavior of Columns with Grouted Bar Couplers in Idaho ABC Applications

Arya Ebrahimpour, P.E. • *Idaho State University*
Leonard Ruminski, P.E • *Idaho Transportation Department*

In Accelerated Bridge Construction (ABC), one way to connect prefabricated reinforced concrete components is by using grouted bar couplers. In the case of precast bridge columns grouted couplers can be installed at both ends of the column and used to connect with footing and cap reinforcement. Although mechanical bar splices are not new to concrete construction, their use in bridge column connections is currently not recommended by AASHTO design code. To address the performance acceptance of grouted bar couplers in Idaho, a study was funded by Idaho Transportation Department (ITD) and carried out by Idaho State University (ISU). The objectives of this research project were to (a) assess the performance of grouted coupler column connections under Idaho seismic conditions; and (b) to develop recommendations on the use of columns with grouted couplers. To achieve the objectives of the project, several tasks were undertaken. First, the research team performed an extensive literature review of seismic requirements of the column-to-footing and column-to-bent cap connections in ABC applications. Two recent experimental projects were identified as very relevant; these are the work by the University of Nevada, Reno (UNR) and the University of Utah. Both projects concluded that grouted couplers are a viable option in ABC applications in seismic zones. Next, the ISU team developed computer models of the cast-in-place (CIP) column and the precast column with grouted couplers that were used in the UNR project. The computer models predicted the force-displacement behavior of the UNR laboratory columns very well. Using the experimentally-verified computer models, the team performed seismic analyses of three Idaho bridges with (a) CIP columns used as reference, and (b) assuming the bridges have precast columns with grouted bar couplers at the bottom and top of the columns. The bridges were analyzed for seismic accelerations corresponding to the most seismically active location in Idaho (i.e., Montpelier) and a less desirable soil condition of Site Class D. All three bridges with grouted couplers performed well, indicating that grouted couplers provide viable option for precast column connections in seismic conditions encountered in Idaho. The conclusions of this project, including recommendations, will be soon included in ITD's Bridge Design LRFD Manual. This will provide all Idaho bridge designers with formalized acceptance of this approach to ABC.

Rapid Cost Effective Bridge Replacement Technology: Geosynthetic Reinforced Soil-Integrated Bridge System

Alan Cukurs • *J-U-B Engineers Inc.*

Geosynthetic Reinforced Soil- Integrated Bridge Systems (GRS-IBS) is a new bridge technology within the Pacific Northwest. Through FHWA's "Every Day Counts" (EDC) initiative, this technology is gaining popularity. With numerous local bridges in Idaho in need of replacement, coupled with challenges for funding Local Highway bridge replacements, a cost effective bridge alternative like GRS-IBS technology helps "stretch" funding dollars and get more "bridge for your buck". The bridge elements that GRS-IBS bridges focuses on are the foundation, the substructure, and the approach to the bridge. GRS-IBS bridge foundations consist of reinforced soil foundation. The foundation supports a reinforced soil abutment wall, which directly supports the superstructure. A wide variety of facing materials is used to face the abutment wall. The approaches are constructed with reinforced soil as opposed to a concrete approach slab. This technology has proven to eliminate the typical bump at the ends of the bridge due to differential settlement. This non-traditional technology provides rapid bridge construction with non-specialized construction equipment and non-specialized labor. Construction is insensitive to weather conditions making it ideal for cold weather construction. Cost for construction can be as low as 60 percent for "do-it-yourself" construction, (as some counties in eastern states have demonstrated). Design effort is significantly less than conventional bridge designs. The application of this technology and description of the design and construction of the first two GRS-IBS bridges designed and constructed in Idaho will be presented. The lessons learned in design and construction; the costs and benefits; and nuances of this technology will be discussed. Addressing Agency concerns for the application of this technology will be presented. The subject bridges are the Tuner Penstock (Penstock) Bridge in Grace Idaho and the North 300-S-Canal (S-Canal) Bridge in Jerome Idaho. Both are precast voided slab bridges using GRS-IBS technology. Both bridges were constructed during winter. The Penstock Bridge was the first GRS-IBS Bridge and provided lessons learned for the second bridge. The Penstock Bridge demonstrates this technology can accommodates highly skewed bridges. With FHWA EDC's grant funding, the S-Canal Bridge is the second GRS-IBS bridge designed and constructed in Idaho. The grant was used to design the bridge and develop Standard Example Drawings and Specifications for Local Agencies to use on future GRS-IBS Bridges. These drawings and specifications will be summarized in this presentation. The S-Canal Bridge was constructed without cast-in-place concrete at the bridge site, without concrete formwork and without steel reinforcement. The duration of actual construction of the S-Canal Bridge from demolition of the existing bridge and replacement with a GRS-IBS bridge was seven weeks. In spite of the learning curve, Thanksgiving holiday, and the snow, the Contractor was able to complete this project at a rapid pace. We estimate that this bridge could have been constructed in 5 weeks.

7C BRIDGE RESEARCH

Design and Configuration of Jointless Bridges for ABC Applications

Behrouz Shafei • *Iowa State University*
Brent Phares • *Iowa State University*
Michael Dopko • *Iowa State University*
Shahin Hajilar • *Iowa State University*

One of the main factors that adversely affect the strength and durability of highway bridge structures is the presence of expansion joints at bridge support locations. The gap that the expansion joint provides is a major route for the ingress of corrosive agents that cause premature deterioration of reinforcing steel and subsequently the rest of the structure. Link slabs are a solution to this problem as they replace conventional expansion joints and create a continuous deck system while the underlying girder system remains simply supported. The cost and maintenance advantages of a bridge with link slabs are well documented through various research efforts. There is, however, a research gap in the available literature concerning the structural demand that a link slab places on the global bridge structure. This subject was investigated by the ISU research team through generating a full-scale 3D Finite Element (FE) model of an existing bridge in need of improvement in Iowa. One of the main conclusions of this case study was that the replacement of expansion joints with link slabs will be an attractive option, particularly in multi-span bridges with bearing pads that act as a pinned connection. While the case study successfully provided detailed information about change of demand on the substructure when link slabs are used, a systematic investigation was needed to characterize the expected demand, determine the structural response, and evaluate the feasibility of the use of link slabs for a diverse group of bridges. The current study tackles this research need by extending the former investigations to a matrix of bridges with various structural configurations and details. A comprehensive analysis is conducted, incorporating a range of loading conditions, which capture the effects of dead, live, and temperature gradient loads. Moreover, a sensitivity analysis is presented, in which the effect of a number of parameters, such as adjacent span ratio, support configuration, skewness angle, bearing pad, and link slab materials, are examined on both super and substructure of the bridges under consideration. Considering the promise of link slab to not only improve the service life of bridges, but also expedite the construction of them, the provided recommendations are expected to greatly facilitate the use of link slabs for ABC projects.

Performance of General Anchorage Zone for Post-tensioned Box Girder Bridges

Ahmed Maree • *University of Nevada, Reno*
David Sanders • *University of Nevada, Reno*

Post-tensioned box girder bridges are very common form of bridge construction. An area that is critical to their performance is the anchorage zone. Very large forces are applied to the box girder and then spread till uniform stress distribution is obtained within the box section. The spreading of the large compressive forces creates tension forces that must be accounted for in the design. The anchorage zone for any prestressed member consists of two zones: local zone and general zone. The end diaphragm is a part of post-tensioning general anchorage zone; it needs to have adequate reinforcement and proper concrete placement. Dimensioning and detailing of box girders end diaphragm are critical for proper performance of post-tensioned bridges. Current reinforcement detailing techniques have led to highly congested anchorage zones with construction issues and cracking problems. In order to study the performance of anchorage zones, four box girders end zones were instrumented in the field in California. These four bridges cover wide variety of anchorage zone configuration including different diaphragm thickness, number of girders, box girder height and openings in the end diaphragm. Strain gauges were used in order to capture stresses in reinforcing bars and strains within the concrete elements. End diaphragm cracking was observed during post-tensioning for the investigated bridges. The field investigation led to the measurement of the actual flow of strains in the general anchorage zone. Through these strains, the flow of forces was determined. Also experimental work was conducted at the Large Scale Structures Laboratory at University of Nevada, Reno. These experimental investigation included two phases. The first one included two single girders half scale I-sections with rectangular solid end diaphragms. The main parameter investigated in these specimens was the diaphragm thickness. The second phase contained two double girder half scale box section with different openings in the end diaphragms as well as one solid diaphragm as a reference for comparison between single and double girder performances. Loading was applied with post-tensioning tendons to represent different design levels as well as to reach the ultimate load of the anchorage zone if possible. Failure load was determined for the second phase specimens, which were double girders with openings in the end diaphragm. Finite element models were developed for the experimental specimens using TNO-DIANA. Results of the developed models showed good correlation with the experimental results of tested specimens. These models were used to extend the investigated parameters affecting performance of general anchorage zone including box girder height, tendon inclination and number of anchors. Safety margin during construction was determined and realistic models were developed to understand the behavior of the general anchorage zones. Finally, design recommendations for the general anchorage zone of box girder bridges were developed including minimum requirements for element dimensions and minimum reinforcement. This study will focus on the field investigation results, and provide important points from the laboratory and analytical study.

Standards to Control Fracture in Steel Bridges Through the Use of High-Toughness Steel and Rational Inspection Intervals

Ryan J. Sherman • *University of Nevada, Las Vegas*
William Collins • *University of Kansas*
Robert Connor • *Purdue University*

Non-redundant steel bridge systems have been used for major bridges in the United States since the late 1800's. Designers recognized the inherent structural efficiency and economy associated with two-girder and truss systems. Unfortunately, early knowledge was limited regarding fatigue, fracture, and overall system behavior; subsequently, a small number of these structures experienced fatigue and fracture issues leading to the creation of the Fracture Control Plan (FCP). The FCP resulted in more stringent design, material, fabrication, and inspection requirements for non-redundant steel bridges; specifically, a 24-month interval for hands-on inspections as established as mandatory for all fracture critical members. Significant advances have been made over the past 40 years since the original FCP was introduced. Developments in fracture mechanics, material and structural behavior, fatigue crack initiation and growth, and fabrication and inspection technologies now allow fracture to be addressed in a more integrated manner. Through these advances, it is now possible to create an integrated FCP, combining the intent of the original FCP with modern materials, design, fabrication, and inspection methodologies. The current study is focused on the development of new design standards which founded an integrated approach to prevent fracture in steel bridges through the use of hightoughness steel. The project is comprised of small-scale material testing, full-scale fracture testing of steel bridge axial and bending members, three-dimensional finite element modeling, and an analytical parametric study. Results from this research demonstrate how rational inspection intervals can be calculated to allow for a better allocation of owner resources while also leading to increased steel bridge safety. (1) Ryan J. Sherman, Ph.D., Assistant Professor, Department of Civil & Environmental Engineering and Construction, University of Nevada Las Vegas, Las Vegas, NV, 89154. Email: ryan.sherman@unlv.edu, Corresponding Author (2) William N. Collins, Ph.D., P.E., Assistant Professor, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, Lawrence, KS 66045. Email: william.collins@ku.edu (3) Robert J. Connor, Ph.D., Professor, Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907. Email: rconnor@purdue.edu

7D BRIDGE MAINTENANCE AND DESIGN POLICIES

MASH Implementation for California Bridge Railings

Tom Ostrom • *CalTrans*
Gregory Kaderabek • *CalTrans*

This presentation will share details of how California plans to design and crash test new bridge railings to comply with the guidelines in the Manual for Assessing Safety Hardware (MASH). In 1993, AASHTO approved the guidelines outlined in NCHRP 350 as the standard for crash testing. Most bridge railings in California are approved under NCHRP 350. In 2009, AASHTO released the first edition of the Manual for Assessing Safety Hardware (MASH). The second edition of MASH was released in 2016, with the requirement that bridge railings approved under NCHRP 350 will no longer approved for new construction by the timeline outlined in the implementation agreement. The California Department of Transportation (Caltrans) adopted an implementation schedule confirming that all new permanent installations and replacements of bridge railings on the California State Highway System advertised on or after October 31, 2019, must comply with MASH criteria. There are many changes between NCHRP 350 and MASH, including changes to the test vehicles, test impact conditions and evaluation criteria. These changes have resulted in an increase in the minimum height for vehicular traffic railings in Test Level 4 (TL-4) locations from 32" to 36". For Test Level 2 (TL-2) locations, the minimum railing height is increasing from 27" to 32" above the roadway for vehicular traffic railings and above the top of the walkway for combination railings. Caltrans is using state research dollars and the Caltrans testing facility in West Sacramento to develop the following MASH-compliant bridge railings: 1. Concrete Barrier Type 732SW (TL-2, h= 32" above the sidewalk). This is a combination railing. It includes a solid concrete parapet with tubular hand railing and an integral raised sidewalk. This barrier is MASH approved and was added to the Caltrans Standard Plans, January 2017. 2. California ST-70 SM (TL-4, h=42" above the roadway). This is a side-mounted steel post and beam vehicular bridge railing. The design utilizes compressible discs at the posts to dissipate energy from a collision load. Testing is complete. Approval pending. 3. California ST-75 (TL-4, h= 36" vehicular, or h=42" bicycle). This is a steel post and beam vehicular bridge railing that can be modified for bicycle traffic. The design is complete. Crash testing is pending. 4. Concrete Barrier Type 85 (TL- 4, h= 36" vehicular, or h=42" bicycle). This is a concrete post and beam vehicular bridge railing that can be modified for bicycle traffic. The design is complete. Crash testing is pending. 5. Concrete Barrier Types 836/842 (TL-4, h= 36" or 42"). These are solid concrete parapet barriers with a 9.1 degree single slope on the traffic face. This presentation will share technical aspects regarding the analysis, design, dynamic modeling and crash testing of these five bridge railing systems.

Successful Preservation Practices for Steel Bridge Coatings

Raymond Bottenberg, Oregon Department of Transportation

Domestic Scan 15-03 was chartered to encourage the use of best practices for bridge coating work. The scope of the investigation included surface preparation and coating application, as well as coating material selection, project type selection (i.e. spot/zone/overcoat vs. full removal/recoat), salt remediation, ambient conditions, and compliance with safety and environmental regulations. These best practices are in turn reflected in recommendations for coating specifications.

Seismic Risk Analysis of Ferry Terminal Bridge Structures

Jeri Bernstein • *Washington State DOT*
Chris Stearns • *Washington State DOT*

Washington State Ferries which is a division within WSDOT is the largest ferry system in the United States. Washington State Ferries provides service to millions of passengers and vehicles annually. This ferry system is part of the Washington State Highway system and comprises 20 terminals throughout the Puget Sound region. These terminals encompass a number of assets, over 750 in total. A large portion of these assets are classified as bridge structures and are designed per the AASHTO codes. These bridge structures have been constructed in different years and are at varying levels of condition. Washington State Ferries is developing a method of prioritizing these bridge structures for preservation and or replacement. The Washington State Ferries system is located within a region of faults with high potential for seismic activity. As a result, the seismic risk aspect is highly influential in the planning and prioritization of bridge structure replacement projects. Each bridge structure is evaluated to determine its resiliency to code-specified seismic demands. (72 year event, 224 year event, 475 year event, 1000 year event) In addition the consequence of the bridge structure being out of operation due to a seismic event at each demand level is also evaluated. There are specific costs with the bridge structures being out of service. These costs include loss of ridership, repair of the bridge structures, and the length of time to repair the bridge structures. The consequence of a bridge structure being out of service at a given seismic demand level is the basis for calculating seismic risk. Bridge structure seismic risk is a crucial element in the Washington State Ferries Asset Management Model. The Asset Management Model is utilized to identify bridge project replacement scenarios. The model maximizes the benefit-cost of proposed bridge replacement projects for long-term planning. This presentation will detail the process of how seismic risk is determined and its inclusion in the Asset Management Model.

8A BRIDGE DESIGN AND CONSTRUCTION

Constructing the SR520 Floating Bridge

Jason Pang • *KPFF Consulting Engineers*
Greg Hess • *KPFF Consulting Engineers*

The SR520 Floating Bridge and Landings Project designed and constructed the world's longest floating bridge, spanning 7,708.5 feet across the deep waters of Lake Washington in Washington State. The original bridge, built in 1963, outlived its useful service life and was vulnerable to storm and seismic damage. The new replacement bridge provides a safer, more resilient connection between Seattle and the growing high-tech cities on the east side of the lake. Construction required innovation married with a highly orchestrated construction process to tackle the challenges of limited site access, extensive overwater work, and an accelerated schedule. By using prefabricated elements, multiple construction activities could take place simultaneously, which accelerated construction, took advantage of water access, and reduced the amount of wet concrete cast over the lake and transported to the site. The efficiencies of both land and water access and marine and traditional construction techniques were maximized. The west end of the bridge was constructed in parallel to the east end, the only side with land access. A string of three pontoons were joined and moored alongside the new east end, providing land access for construction activities from the new roadway deck. In one morning, the completed 1,000-foot-long bridge section was slowly pushed in place as a single unit, completing the full length of the bridge. Ongoing collaboration between the contractor, engineer, and naval architect, was required to ensure freeboard and concrete stresses in the pontoons were maintained within acceptable limits at all times. Continuous construction staging analysis checked over 1,500 unique construction steps throughout construction to ensure the bridge was stable at all times and properly ballasted. In addition, special construction engineering and structural analysis of the structure allowed the contractor to use heavy equipment on the new bridge, typically not allowed in most bridge construction. The floating highway is supported on a backbone of 77 precast concrete pontoons, the largest and heaviest every built, some weighing over 11,000 tons. Massive anchors permanently moor the structure to the lake floor mud, and an elevated roadway superstructure keeps motorists above storm surges, while providing crews access below. The center mile of roadway superstructure features a unique post-tensioned segmental precast ribbed deck panel system and the ends connecting the approaches features traditional column/crossbeam prestressed girder bridge structures. Two steel transition spans link the stationary landings and accommodate substantial bridge movements. The new bridge was open to traffic in April 2016.

Design of Pre-Cambered Concrete Girders with Moderate to High Levels of Pre-Camber

Amanda Wong • *COWI North America, Inc.*
Claudio Osses • *COWI North America, Inc.*

The use of pre-cambered prestressed concrete girders (precambered girders) is an effective solution that can lead to significant cost savings in projects with tight vertical clearance and length constraints. Pre-cambered girders have been used in multiple projects in the State of Washington, such as the Tonquin Avenue Bridge and Razor Clam Bridge in Ocean Shores; and SR519 Royal Brougham and South Lander Bridge in Seattle. In all these bridge projects, the use of pre-cambered girders has benefited the project by eliminating the need for in-water piers, allowing for the use of longer spans and/or shortening the project limits. Pre-cambered girders are similar to standard non-precambered prestressed concrete girders (standard girders) except that the total camber in pre-cambered girders is the sum of the natural camber from the prestressing and the additional pre-camber built into the girder formwork during the girder fabrication. The introduction of this pre-camber allows prestressed girders to follow the roadway profile maximizing the vertical clearance for a given girder depth. Fabrication of pre-cambered girders is similar to that of standard girders except that they are fabricated using a series of straight formwork segments arranged to create a chorded girder profile that approximately follows the curved girder profile specified in designs. The straight strands layout in pre-cambered girders is similar to that of standard prestressed girders, except that the straight strands are not actually straight since they are installed parallel to the chorded profile of the girder. The chorded layout of the straight strands causes localized downward forces at each of the straight strand kinks. The harped strand layout in pre-cambered girders is similar to that of standard prestressed girder, expect that the eccentricity of the harped strands does not vary linearly along the girder as it is affected by the girder pre-camber. For pre-cambered girders with low levels of pre-camber, a similar analysis and design method as the one used for standard girders can be used for design. For pre-cambered girders with moderate to high levels of pre-camber, the following additional items unique to pre-cambered girders need to be considered in the design: (1) non-linear variation of harped strand eccentricity; (2) reduced deck haunch thickness; (3) higher girder CG in stability calculations during transportation; (4) downward reaction at straight strand kinks; (5) leveling detailing at bearing locations. Items (1), (2), and (3) can be handled with an envelope analysis approach using a standard prestressed girder design software such as PGSuper. Item (4) requires conventional force deviator design in combination with a local Strut and Tie model. Item (5) requires the design of a leveling plate or similar to be added to the bottom of the girder at the bearing locations. Despite their proven benefits, pre-cambered girders are still underutilized by bridge designers, in part due to the lack of familiarity with their benefits, fabrication and design. This presentation will attempt to further the understanding of pre-cambered girder among bridge designers by presenting a specific design approach methodology for pre-cambered girders with moderate to high levels of pre-camber.

Predicting Major Bridge Construction Costs

Ken Saindon • *EST, Inc. - Colorado Bridge Group Manager*

How much will a planned bridge cost? Can future bridge costs be reasonably extrapolated from historical bridge cost data? Is one bridge type inherently more cost-effective than another? These are questions bridge owners would like to know for programming of funding. This presentation will answer these questions by proposing a bridge construction cost model that combines the existing RS Means Location Index with new indices for inflation, material consumption, and structure type. A database of historical construction costs for approximately five dozen major bridges, normalized to dollars per square foot of deck area, forms the basis for the proposed construction cost model. The data features bridges that vary by bid year, material of construction, structure type, geographic region, and project delivery method. The raw cost data will be discussed only briefly. Comparisons of interesting structure pairs will be presented to isolate the effect of each term in the construction cost model. The material consumption index is developed to account for increased square footage costs as bridge span lengths increase. The inflation index is developed based upon a proprietary money flow indicator derived from financial system data. This index differs radically from previously published indices such as ENR or Producer Price Index as well as any uniform exponential growth rate. The lagged effect of inflation will be discussed. Calibration of the inflation index is demonstrated using the best available historical bridge construction cost data for similar structure pairs. The presentation features extensive photographic support of many of the bridges in the cost database to allow audience members to gauge the historical bridge costs relative to the bridge site constraints. The audience will enjoy the photographic support as well as the graphical depiction of the cost indices. Overall, the presentation will demonstrate that future bridge construction costs can be normalized and reliably extrapolated across time, geography, span length, and structure type using the historical cost data. A definite pecking order can be seen in terms of structure type versus historical bridge construction costs. Note to reviewers - I have categorized this presentation as being most relevant to "bridge management and performance measures" per the choices on your website.

8B BRIDGE RESEARCH

Reliable Fit-Up of Steel I-Girder Bridges

Domenic Coletti • *Michael Baker International*
Don White • *Georgia Tech*
Thanh Nguyen • *RS&H*
Brandon Chavel • *HDR*
Micheal Grubb • *M.A. Grubb & Associates, LLC*
Calvin Boring • *Brayman*

This presentation summarizes recently completed research supporting the development of improved design, detailing and erection guidelines to ensure reliable fit-up of skewed and/or curved steel I-girder bridges. Twenty-one bridges, including multiple framing arrangements on a number of the bridges, were analyzed to provide quantitative support for, and refinements to, guidelines produced by an affiliated National Steel Bridge Alliance (NSBA) Steel Bridge Collaboration Task Group. The quantitative data of this research support recommended fit conditions (aka, cross-frame detailing methods), as a function of the bridge geometry. Forces required to assemble the steel during erection were evaluated and difficult cases highlighted. Suggested erection considerations to facilitate fit-up were provided. In addition, the research investigated and specified beneficial staggered cross-frame arrangements for straight skewed bridges, as well as framing arrangements around bearing lines at interior piers in continuous-span bridges. The research placed an emphasis on identifying the impacts of the chosen fit conditions on girder elevations, girder layovers, cross-frame forces, girder stresses, and vertical reactions in completed bridge systems. Simplified methods of accounting for Steel Dead Load Fit (SDLF) and Total Dead Load Fit (TDLF) detailing effects were provided. In addition, procedures were developed and explained for direct calculation of the locked-in forces due to SDLF and TDLF detailing in cases where a more precise calculation of these effects may be beneficial. Lastly, construction inspection best practices were recommended to ensure that the erected geometry sufficiently meets the specified fit conditions, and recommended design specification provisions were developed that synthesize the key guidelines.

Concrete-Filled Tubes for Improved Seismic Performance and Constructability

Dawn Lehman • *University of Washington*
Charles Roeder • *University of Washington*
Bijan Khaleghi • *WSDOT*

In urban regions, use of modular construction improves efficiency, reduces errors and costs of structural systems. Typical modular systems utilize primarily precast elements. Although precast systems are advantageous, they require specialized equipment and customized forms. Concrete filled tube components can replace precast piers and piles with the advantage of simplifying construction (eliminates the need for a core reinforcing cage and formwork). However, design of CFTs have not been developed and validated to the same extent as other, more traditional construction systems. Shortcomings with current CFT design are: (1) lack of consistent design expressions for the strength and stiffness of CFTs, (2) need for standard and reliable connections to precast and cast-in-place substructure and superstructure components, and (3) severe underestimate of the shear strength. The University of Washington has been investigating CFT properties and their connections over the past decade, resulting in new design expressions; these expressions that have been implemented in AASHTO specifications and the WSDOT Bridge Design Manual, and are under consideration for implementation by Caltrans. The presentation will provide an overview of the research results, the design methods and expressions and impact on constructibility. A system-level, comparison of the seismic performance of CFT and RC bridges (moment frames) will be discussed and used to demonstrate the superior response and resilience of the CFT bridges. Note that this could be categorized under the following: (1) ABC, (2) Bridge Design and Construction (3) Seismic Design, and (4) Bridge Foundation Analysis and Design.

Alternative ABC Connections Using UHPC

Mohamadreza Shafieifar • *Florida International University*
Mahsa Farzad • *Florida International University*
Atorod Azizinamini • *Florida International University*

Accelerated Bridge Construction (ABC) is a method of bridge construction designed to reduce traffic interruption, minimize onsite construction time, and increase safety at work zones. One solution to accelerate and facilitate the construction is by utilizing precast elements. However, connections between prefabricated elements could be a challenging issue, especially in seismic regions. Ultra-High Performance Concrete (UHPC) has several superior characteristics that can assist in the implementation of ABC in practice, such as rapid early age strength gain, and anchorage of reinforcement over a very short period. This paper proposes an innovative connection between a precast column and cap beam for seismic and none-seismic areas, which can potentially satisfy constructability requirements and expected seismic performance. The main characteristics of the proposed connection for seismic detail are desired plastic hinge location and large construction tolerances. Experimental tests were performed to evaluate the performance of the proposed connection. Results of the tests indicated the acceptable behavior of the connection under cyclic load and demonstrated the formation of plastic hinges in the desired location. The observed displacement ductility exceeds those implied by design specifications. The most interesting aspect of the proposed detail is the certainty associated with where plastic hinge forms and its length. This objective is achieved by sandwiching a certain length of the column, using normal strength concrete (plastic hinge region) in between two layers of Ultra High Performance Concrete (UHPC). The behavior of the proposed connection has been further investigated by using nonlinear finite element analysis. This presentation will provide a description of the proposed ABC connection detail for both seismic and non-seismic applications as well as design provisions. This project is a part of ABC-UTC (www.abc-utc.fiu.edu) research studies being carried out at Florida International University.

8C BRIDGE SEISMIC DESIGN

Earthquake Duration Effect on Collapse Capacity of Reinforced Concrete Bridge Columns

Mohammed Mohammed • *Dynamic Isolation Systems*
David Sanders • *University of Nevada, Reno*

The recent earthquakes that occurred in Indonesia, Chile, and Japan are reminders of the possible occurrence of a long-duration large-magnitude earthquake near the Cascadia subduction zone along the United States Pacific northwest coast. The importance of studying the effect of ground motion duration on structures has been highlighted after these earthquakes. Current seismic design provisions do not consider ground motion duration effects on structures. Moreover, conclusions from previous research studies with regard to the effect of ground motion duration on structural performance have been conflicting. Comprehensive experimental and analytical studies to investigate the ground motion duration effect are presented. The results of shake table tests of four identical large-scale reinforced concrete (RC) bridge columns are discussed. The columns were tested using spectrally equivalent long and short-duration ground motions. In the post-test analysis, an OpenSees model was used and calibrated against the experimental results. The model takes into account the low-cycle fatigue effect. Incremental dynamic analysis was employed using 336 spectrally equivalent long and short-duration motions. Comparative collapse analysis was done by developing collapse fragility curves using different spectral acceleration intensity measures. The results show that ground motion duration has a significant effect on the collapse capacity of RC bridge columns. Therefore, it is recommended to consider the duration effects in the seismic design provisions, especially in regions where long duration earthquakes are potential risk. Preliminary design recommendations that include duration effect are proposed.

I-5 Overcrossing (Cook, Over PNWR) Seismic Retrofit Design and Phase II Construction

Michael Roberts • *HDR Engineering, Inc.*
Mark Libby • *HDR Engineering, Inc.*

The completion of Oregon's first Phase 2 seismic retrofit project has provided a valuable opportunity to review and reflect upon the seismic retrofit design approaches taken for a handful of bridges servicing the Interstate-5 lifeline in the Portland Metro area. The intent of this presentation is to focus on the details of a recent seismic retrofit and prescribed procedure, including analysis and design measures undertaken to increase seismic resiliency of one of the bridges delivered as part of a larger package to meet the 500-year operational performance level and 1000-year life safety performance requirements. Originally constructed in 1937, the two-lane, thirty-six foot wide three-span concrete girder Cook Overcrossing (over PNWR) was modified and widened three times over the last eighty years to meet increasing I-5 traffic demand. Widening efforts in 1953 and 1973 followed by a widening, deck raising, and overall bridge lengthening in 1988 has resulted in an eight lane, one-hundred and fifty foot wide bridge having a twenty-six degree skew. Due to the sequential bridge widenings and span configurations, a wide variety of foundations present at the abutments and the in-span piers presented geometric challenges for soil structure interaction and seismic analysis and design approaches. In addition to a multitude of spread footings sizes and locations, multiple discrete pile caps of various sizes mixed with timber and precast concrete piles support the bridge at in-span piers and abutments. The first half of the presentation/paper will cover analytical approaches taken to address the soil structure interaction of the three span skewed bridge, identifying the potential deficiencies, and the approaches taken to arrive at the retrofit design solution which would work with the variable components of the bridge and uphold the seismic performance goals. The second portion of the presentation/paper will explore the construction phase which uncovered unforeseen field foundation conditions and will discuss the reactive design approaches taken to address and adapt the retrofit design to meeting the project goals while mitigating construction delays and cost increases. Performance-based seismic design applied to the project will be discussed and evaluated with simple seismic checks and balances which facilitated a cost-sensitive approach while meeting project goals for resiliency and survivability.

Dynamic Interaction of Bridge Superstructure and Light Rail Vehicle

Aamir Durrani • *HNTB Corporation*
Hao Luo • *HNTB Corporation*
Ziaoyun Wu • *IDC*

Based on Los Angeles County Metro Rail (Metro) design criteria to avoid resonance and to provide passenger comfort when a bridge structure has its first- mode natural frequency of vertical vibration less than certain threshold (3 Hz for consecutive span number greater than or equal to three), an analysis of the dynamic interaction between vehicles and the aerial guideway (bridge) structure shall be performed. For this type of analysis normally a sophisticated computer model which can simulate the transient load transfer mechanism between a guideway structure and moving vehicles considering primary and secondary suspensions is required. By incorporating the vehicle's inherent properties of the primary and secondary suspensions to the bridge superstructure, this paper presents a rolling-stock analysis with a simplified structure-vehicle interaction finite-element model using SAP2000/CSiBridge computer program and determines the dynamic amplification factor for a Light- Rail-Vehicle (LRV) traveling over a four-span post-tensioned concrete haunched box girder bridge with constant speed of 55 mph. Guideway structure dynamic amplification and the indication of the passenger comfort are discussed.

8D BRIDGE ANALYSIS AND DESIGN

Foundation Restrained Analysis of Bridge Structures for Liquefaction Induced Lateral Spreading Soil Load

Ahilan Selladurai, PE, SE, PMP, SECB • *T.Y. Lin International*

Liquefaction and lateral spreading is always a potential high-risk issue for infrastructure developments in high seismic areas. Pervious earthquakes have severely damaged and even collapsed bridges by causing liquefaction induced lateral spreading of the soil. The liquefaction caused lateral spreading which creates higher displacement/force on foundations which resulted in the damage. Many studies have been conducted about this topic by several researchers and institutions. For many years, the engineering practice was to perform free soil movement analysis for liquefaction induced lateral spreading. However, this method is a more conservative approach and requires high cost replacements or heavy retrofits instead of other less costly retrofits alternatives. Analysis tools and general guidelines on foundation restrained liquefaction induced lateral soil movement analysis are very limited until recent Caltrans guidelines. Caltrans published new guidelines to analyze both existing and new bridges for either foundation restrained soil movement or free soil movement in 2011 initially and issued updates in later years. Foundation restrained lateral spread analysis requires collaborative approach between geotechnical engineer and structural engineer.

The foundation restrained analysis method reduces the overly conservative assumptions of the conventional free soil movement analysis. Balanced demand for lateral spread movement due to liquefaction is where when required resistance to avoid sliding (By geotechnical engineer) and provided resistance by foundation (By structural engineer) are balanced, this is the balanced demand for lateral spread movement due to liquefaction. This type of analysis assumes structures provide resistance to soil wedge failure, and balanced lateral soil movement demand is significantly less than free lateral spread demand.

Further, structures are typically designed for "no-collapse" and for 975-year return period earthquakes. No-Collapse criteria requirements for embedded structures were not clear until Dec 2016 Caltrans guidelines.

This presentation will include experience during 26 span, 650 ft. long, 3 frames, and 50 year old bridge seismic retrofit project design and preliminary studies performed to determine appropriate seismic retrofit strategies based on restrained lateral spread analysis.

A Case Study on Extreme Scour at an Alaska Bridge and the Monitoring Efforts Used to Track the Changing Conditions

Michael Knapp, P.E. • *Alaska Department of Transportation & Public Facilities*
Jeff Conaway • *USGS Alaska Science Center*

In 2011, the Alaska Department of Transportation and Public Facilities (DOT&PF) closed Bridge No. 339 over one branch of the Copper River delta due to extreme scour. This presentation will cover the hydrologic and hydraulic conditions that contributed to the extreme scour conditions, the approach taken to track the progression of scour, the internal analyses and deliberations leading to closure of the bridge, and visual records of the erosion processes in action. The U.S. Geological Survey (USGS) played a key role in the monitoring effort and this presentation will also discuss the agreement in place between the Alaska DOT&PF and the USGS that allowed that jointly-funded collaboration to happen. Bridge 339 is one of eleven bridges crossing the wide Copper River delta. The flow distributions between the delta bridges have changed over time, occasionally leading to severe erosion and, in the case of Bridge 339, structural vulnerability due to scour. The design files and asbuilt drawings for Bridge No. 339 indicate that the designers viewed the (nominal) "100-year" discharge value to be 21,300 cfs. The Copper River is capable of flows approaching 450,000 cfs. Geomorphic changes in the braidplain led to flow redirection towards Bridge 339, during the Summer of 2010, the USGS measured sustained discharges above 80,000 cfs through the bridge opening. Portions of the Copper River basin are glacierized, and there are periodic jökulhlaups (glacial outburst floods) that have contributed to the peak streamflows on record. The reach near Bridge 339 is also prone to ice-jams. Monitoring efforts to track scour conditions included pier-mounted sonars, sounding and discharge measurements, on-site observations, bathymetric surveys, and aerial reconnaissance. Following the closure of the bridge, digital cameras mounted on the river bank captured the loss of about 1000 feet of the bridge approach embankment during the 2013 Spring breakup.

Investigation of Buckling Analysis Methods for Oregon Arch Bridges

Benjamin Blasen, P.E. • *CH2M*
Joe Stith, P.E • *CH2M*

During development of arch bridge load rating procedures for the Oregon Department of Transportation, the CH2M team found limited guidance in the AASHTO LRFD Bridge Design Specifications for determining arch buckling loads which are necessary for member capacity determination in load rating calculations. AASHTO specifications do not currently include guidance for analysis of steel tied arches and moment tied arches, nor do they address buckling analysis of bridges with variable arch section properties. Additional research was completed to evaluate industry recommendations, engineering software capabilities, and arch buckling provisions in other codes. This presentation describes both the basic AASHTO arch buckling methodology and advanced arch buckling methodologies and reports and compares the results obtained from the different methodologies for various types of Oregon arch bridges.

9A BRIDGE DESIGN AND CONSTRUCTION

Design and Construction of the Tilikum Crossing in Portland Oregon

Norman Smit • *T.Y. Lin International*
Kevin Almer • *T.Y. Lin International*

This presentation will address the state-of-the art approach to the design and construction of the Tilikum Crossing, Bridge of the People. A general overview of the design considerations showing the impact of construction on the design, and how the means and methods of construction impact the final dead load and geometry of the bridge.

Structural Design of Main Post Cut & Cover Tunnels – Presidio Parkway

Allen Rejaie • *HNTB, NorCal Structures Dept. Manager*

Doyle Drive, originally built in 1936, contemporaneously with the construction of the Golden Gate Bridge, was structurally and seismically deficient and a high priority for replacement. Presidio Parkway project includes constructing a new roadway to replace about 1.6 miles of the existing U.S. 101, from the south approach to the Golden Gate Bridge to the vicinity of the Palace of Fine Arts in San Francisco. The new 6-lanes parkway will provide a vital transportation link between the North Bay counties, San Francisco, and the Peninsula. The project includes the construction of 9 bridges and 2 tunnels, Main Post and Northbound Battery Tunnels. The focus of this study is on the structural design complexities of the Main Post Tunnels. This study demonstrates structural design challenges listed below and reviews some of the solutions that were employed by the design team: a. Design coordination for the major ground improvements due to liquefiable soil b. Design for fire loading c. Over-burden soil and SSI issues d. Accommodating overpass at the widest section of the tunnels e. Expedited construction schedule that impacted the design f. Uneven length of the tunnels and lateral displacement issues g. Performing work at water table elevation h. Landscaping and waterproofing of the tunnel When completed, Presidio Parkway will improve structural, seismic, and traffic safety along this section of U.S. 101. The following picture shows east portal of Main Post Tunnels.

Balancing Innovation, Constructability, and Maintenance to Cross the San Diego River

Nathan Johnson, PhD, PE • *Kleinfelder*
Kelly Burnell, PE • *Kleinfelder*

Construction is underway to add a second main-track along a critical rail corridor in San Diego, California. The centerpiece of this $100M project is a 1000-foot-long coastal bridge crossing the San Diego River. This presentation will describe how project challenges were addressed both technically and from a project management perspective. The site is underlain with challenging ground conditions including up to 70 feet of seismically-liquefiable material, and 60 feet of material prone to static surcharge settlements. Alignment, profile, and seismic constraints led to a through-girder bridge with relatively long spans. Innovative bridge piles were selected where permanent steel casings were used not only for improved constructability, but for strength and stiffness. Settlement-prone approach soils were a concern for both track embankments and existing urban structures. Several alternatives were studied in detail, including additional bridges, ground improvements, and lightweight fills. The team worked extensively with the operating agency to ensure operation and maintenance concerns were addressed. Constructability was a major focus considering maintenance of adjacent rail traffic. The final solution was a combination of lightweight concrete fill supported on approximately 60-foot-deep ground improvement. Combined, the innovative use of piles and application of lightweight fill saved over 15 percent in construction cost. In addition to technical discussion, this presentation will provide an overview of how the CMGC method was applied for the SDRBDT and why the process was a success. Logistics between the multiple project design teams and the CMGC team will be described, along with benefits of the CMGC process as observed for this project. Also, from the design team perspective, CMGC lessons learned during the delivery phase, GMP phase, and construction phase will be summarized.

9B ACCELERATED BRIDGE CONSTRUCTION

SH-97, I-90 OPASS IC #22

Shawn Metts • *HMH Engineering*
Jacob Hall • *HMH Engineering*
Nate McKinley • *Idaho Transportation Department*

The Idaho Transportation Department (ITD) has a sustained history of implementing some of the most advanced and innovative bridge design and construction techniques known in the industry. This bridge designed by and constructed for ITD on the SH-97, I-90 OPASS IC #22 project is no exception as it exemplifies ITD's commitment to providing safer, more cost effective, and less impactful construction solutions to meet the growing public and commercial road user demands of our nation.

This exemplary bridge was constructed in multiple stages on State Highway 97 and spans 207-feet over 4-lanes of Interstate 90. It was constructed in 2016 and is located approximately 10 miles east of Coeur d'Alene, ID in Kootenai County. As a result of structural deterioration and substandard vertical freeway clearances, the successful objective of this project consisted of replacing the existing bridge, built in 1960, with a new 43-foot wide multi span bridge utilizing Accelerated Bridge Construction (ABC) techniques to reduce construction time and road user impacts, as well as the use of Innovative Materials to enhance structural durability and increase the life cycle of the bridge. Designed by the late Ken Clausen, P.E. and Umesh Narsinghani, P.E., both from ITD, and constructed by Concrete Placing Company in 100 days for a cost of $4.6M, this multi stage bridge project, including partial reconstruction of the entire SH-97/I-90 Interchange, is a true testament to the ingenuity of ITD and the advantages and positive implications of Materials Innovation and ABC.

To improve site constructability, project delivery time, material quality, and work zone safety, while reducing traffic impacts, onsite construction time, and environmental impact, ITD utilized the Prefabricated Bridge Elements & Systems (PBES) strategy of ABC for the design and construction of the bridge. Having only been partially attempted by ITD on three (3) prior projects, the design and construction of the bridge substructure incorporated the use of pre-cast concrete abutments, wing walls, pier columns, and pier caps which were all fabricated off-site under the strictest of project schedules and quality control procedures. During construction, and as part of the design, the associated pre-cast bridge elements were married together using cast-in-place concrete and closure placements.

The bridge superstructure was designed and constructed in two (2) spans, the southern and northern spans, for a total combined span of 207-feet. Each span of the superstructure consisted of six (6) each pre-stressed deck bulb tee girders which, when installed and joined together, provided the 43-foot width of the bridge. As the first of its kind, ITD utilized Ultra High Performance Concrete (UHPC) to effectively join adjacent girders together; thus, increasing the survivability of the critical joints and reducing long term life cycle costs of bridge and joint maintenance. Once completed and installed, the bridge girders were given a Polyester Concrete Overlay which serves as the wearing surface.

HMH Engineering provided full spectrum consultant Construction Engineering, Inspection, and Testing for ITD on this innovative and unique project and we are hopeful that everyone is provided the opportunity to learn from this project.

I Didn't Know It Would Be That Fast! ABC Advancements and Advantages with Buried Bridges

Joel Hahm • *Big R Bridge*

Structural plate Buried Bridges have been in use for over 80 years. These types of structures were initially developed as a higher quality alternative to traditional culverts for use in hydraulic and minor crossings where culverts could not meet flow and size requirements, bottomless structures were needed, or longer service life was required. 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 low to medium span traditional bridges have typically been used – particularly in the western states. This has been made possible by industry 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 installed costs compared to traditional bridges, ability to carry heavier loads than traditional bridges, increased resilience and seismic resistance through structure flexibility and redundant systems, improved aesthetic flexibility through the use of a wide variety of end treatments, sustainability advantages over most other types of bridge systems, and lower maintenance and inspection costs compared to traditional bridges. Flexible Buried Bridges are an emerging alternative to many low to medium span traditional bridges. Buried Bridge structures fit well into the Accelerated Bridge Construction (ABC) model in terms of quicker lead times for materials, fewer construction steps with no lag time between steps, elimination of deep foundations in most cases, no need for specialized labor or heavy equipment (many counties and GCs prefer to use their own forces), elimination of bridge abutments, and often a smaller construction footprint compared to traditional bridge projects. In some cases it is possible to complete a buried bridge project without delivering concrete to the site. This is especially beneficial in remote areas where it may be difficult or cost prohibitive to mobilize large construction equipment. Flexible Buried Bridges typically will use lower cost and quicker to build foundations than traditional bridge options. Buried Bridges can be easily constructed in phases, eliminating the time and expense with building detours in many cases. Flexible Buried Bridges are by nature ABC bridge systems and should be evaluated as an option for any low to medium span bridge application. The goals of this presentation are to focus on the ABC aspects of design and construction of Buried bridges, including several case studies. Among the specific topics to be discussed are applications, design, cost advantages, ABC, foundations, and innovative construction techniques.

Ohio's ABC Demonstration Project with Rapid Bridge Replacement with Tub Girders Integrated with SPS Bridge Deck. Self-Performing Installations of Short Span Bridges with SPS Bridge Decks.

Rolando Moreau • *SPS North America*
Kay Jimison • *SPS North America*

In Muskingum County Ohio, an existing short-span steel bridge was rapidly replaced by press-braked tub girders integrated with light-weight SPS bridge decks. SPS bridge deck is a prefabricated structural composite deck which is 70% lighter than an equivalent concrete deck. Prefabricated half-width bridge modular elements were delivered to site, erected, assembled and opened to traffic in 5 days. SPS bridge decks are ideal for self-performing installations on short-span steel bridges by state and maintenance crews. The installation of SPS bridge decks is an all-steel construction which requires light-weight construction equipment using a single trade and which has immediate load-carrying capacity for other construction activities or for traffic vehicles.

9C FOUNDATION DESIGN AND CONSTRUCTION

Sellwood Bridge Replacement – Landslide Mitigation

Tom Westover • *Cornforth Consultants, Inc*

This presentation focuses on the Landslide Mitigation component of the award-winning Sellwood Bridge Replacement Project. An anchored shear pile (ASP) system, consisting of 40 6-foot diameter drilled shafts connected with a grade beam and 70 ground anchors with prestressed loads up to 850 kips, arrests an ancient 500-foot wide landslide at the project site. Mitigation of this landslide was necessary to facilitate construction of the new Sellwood Bridge, a three-span steel deck arch that crosses the Willamette River south of downtown Portland. T.Y. Lin International was the Prime Consultant for the final design phase and Engineer of Record for the steel deck arch bridge. Cornforth Consultants was retained to design the landslide mitigation system, and the consultant design team provided additional engineering services throughout construction. The overall project centered on replacement of a historic steel truss bridge, which had been significantly distressed by a slow-moving landslide; records indicate that this landslide had moved approximately 4 feet since construction was completed in 1925. Structural mitigation of landslides is increasingly necessary where existing geologic hazards intersect with displacement-sensitive infrastructure. Conventional shear pile systems require passive resistance be developed by displacement of the landslide. Where displacement of the landslide or structural system is undesirable, anchored shear piles can be used to develop full-depth restraint of large landslide masses with limited post-construction deformation. No published standard for the design of such a system exists, and a typical 'lateral-loading-of-pile' approach can yield inefficient or even unconservative designs. ASP systems take advantage of increasing soil strength and stiffness with depth, to apply much larger ground anchor loads at the surface than could obtained through ground anchors on bearing blocks. In addition, construction of an ASP system can provide full-depth resisting force to a landslide, without the risk and right-of-way impacts of large open-cut excavations. This presentation will cover the design considerations, construction challenges, and instrumented performance of the ASP system constructed for the new Sellwood Bridge. Buried utilities and other future foundations required tight horizontal and vertical control of the installed anchors, so each anchor drill hole was measured to verify position prior to installing the tendon. Landslide monitoring was conducted throughout construction, and additional anchor loading was added through re-stressing of existing anchors and installing new anchors through the grade beam to accommodate the new conditions. The project was administered by and is owned by Multnomah County, and was delivered under the CM/GC contracting method via a joint venture between Slayden Construction Group and Sundt Construction Company. Final design was completed in 2012, and the new structure was opened to traffic in February 2016 with substantial construction completed in January 2017.

Changes to AASHTO LRFD & CALTRANS Design Criteria for Design of Retaining Structures over the Last Decade

Ahilan Selladurai, PE, SE, PMP • *T.Y.Lin International*

Earth retaining structures are one of the major component in infrastructure projects. They have been designed and constructed based on allowable stress design (ASD) criteria for long time and have been found to be safe and cost effective for most applications. The American Association of State Highway and Transportation Officials' (AASHTO) Load and Resistance Factor Design (LRFD) criteria for earth retaining structures have provided a new direction for design of earth retaining systems for engineers and designers in recent years, which is totally different from previous ASD criteria. Implementing AASHTO's LRFD design criteria has significantly changed the estimation and application of earth, surcharge, and seismic loads; evaluation of external stability including bearing pressure and eccentricity; and structural design of elements.

Beginning in 2007, most departments of transportation (DOTs) adopted LRFD design standards, required that their design practices be updated accordingly, and revised their predesigned ASD-standard drawings and details to LRFD-based design. Most earth retaining structures designed based on ASD criteria failed based on AASHTO LRFD criteria. Implementing AASHTO's LRFD design criteria caused the cross section geometry of earth retaining structures to increase significantly, thus increasing the cost of the structures. Several DOTs started to investigate the reasons for this significant increase and issues related to the new LRFD design criteria that caused it. Memoranda were issued to engineers to override particular AASHTO requirements to reduce impacts of design changes. After additional research and investigations, AASHTO requirements were considerably revised in 2010, 2012, and 2014.

This study summarizes the changes to AASHTO's LRFD Bridge Design Specifications from 2007 to 2014 for earth retaining structures, actual impacts on geometry considerations, and construction cost implications. The study also shows the above-mentioned parameters/considerations for conventional retaining walls, tie-back walls, culverts, geo-synthetic walls, and other types of retaining walls. The discussion presents our experience and analysis of design results from work assisting the California Department of Transportation in updating its standard plans and standard detail sheets for many types of retaining walls, based on AASHTO LRFD 2007 standard specifications. Implementing the AASHTO LRFD-2007 criteria resulted in a construction cost increase for retaining walls of about 10% to 30% compared to the cost of implementing the ASD criteria.

Lightweight Embankment Materials for Bridge Approaches

Aamir Durrani • *AISC*
Murali Hariharan • *ASCE*

New construction in developed urban areas sometimes present unique challenges with respect to working around large and significant utilities. In this paper, we bring out a set of challenges that had to be overcome to protect the underground high voltage power lines from settlement resulting from bridge approach embankment construction as part of multi-billion dollar Crenshaw/LAX light Rail Project. These power lines located 5 to 10 feet below grade are the main power feed to the LAX airport. The Manchester Ave UP required construction of a 30-feet high approach embankment over the power lines. The Project's geotechnical consultant predicted ground settlement for this soil embankment to be on the order of 4 inches. This large magnitude of settlement was unacceptable to the owner, the Los Angeles Department of Water and Power and the Los Angeles Metro. This amount of settlement had the potential to cause significant distress to these critical power lines. The design team evaluated several alternatives for the embankment construction to limit the settlement to under 0.25 inches and prevent distress to the power lines. The short-list alternatives included using GEOFOAM with a cast-in-place containment structure or using Light Weight Cellular Concrete (LCC) with a Mechanically Stabilized Embankment (MSE) wall. This paper describes details of the GEOFOAM and LCC alternatives. Both static and seismic design aspects were considered and addressed. The static design was governed by Light Rail Vehicle (LRV) axle loading and allowable settlement of the ground. Whereas, the seismic design was governed by embankment stability and allowable pressures on the GEOFOAM and the LCC. The GEOFOAM and LCC embankments were treated as a single degree of freedom elastic material for seismic design and forces were evaluated using the site specific seismic response spectra derived for the project. The containment structure forces were evaluated using an inertial approach. The MSE embankment was analyzed using the seismic coefficient procedures in AASHTO/CALTRANS for soil structures that can undergo large displacements in a seismic event. The LCC with an MSE containment was the preferred alternative chosen by the Contractor. The embankment construction was successfully completed in early 2017, predicted settlements matched closely with actual values in the field with no adverse impacts to the LAX power lines.

9D PEDESTRIAN BRIDGE PROJECTS

Design and Construction of Long Span Pedestrian Bridges in Remote Sites with Difficult Access

Douglas Sarkkinen • *Otak, Inc.*

This presentation covers three recent (2012 to 2016) trail suspension bridge projects that were constructed in remote areas with difficult access. The first bridge (Crystal Creek Suspension Bridge) was a 150 span suspension bridge over Crystal Creek in the northern region of the Olympic National Park, where a deep canyon did not allow driving access to the other side. The contractor installed a cable trolley system across the canyon to transport equipment and materials. One end of the suspension cables were anchored into a cliff. The second project (Staircase Rapids Pedestrian Bridge) was a 210 foot span pedestrian bridge over the Skokomish River in the southern portion of the Olympic National Park. This bridge was in a wilderness area, so the materials and equipment were transported by helicopter. The materials had to be carefully lowered by the helicopter down through a forest of 200 foot tall mature Douglas Fir trees. The back stays required deep soil anchors which required drilling equipment and grout. Tuned mass dampers were installed under the deck to minimize the effect of unnerving vibrations from foot traffic. The third project (Buckley Waterline Bridge) was a 200 foot span pedestrian bridge over South Prairie Creek that supported a 12 inch diameter water line that serviced the City of Buckley, WA, and was located deep down in a canyon with no road access. The contractor utilized a cable trolley system to lower materials and equipment down into the canyon. The suspension structure was anchored using a unique tripod tower with the back footings buried substantially to provide the necessary uplift reactions. The design phase for each will be discussed, identifying the site constraints and access constraints and why the particular designs were selected. Secondly, the construction phase of each will be discussed, showing how the materials and equipment were brought to the sites and methods the contractor used to erect the bridges. Finally, a summary will be provided that discussed the cost of all three structures, with relative costs associated with the difficult access broken out. The presentation will provide valuable insight for engineers and agencies that are planning future projects such as this, showing the range of possibilities that exist for remote and difficult access sites.

Truckee River Bridge - Tahoe City, CA: A Unique Cellular Abutment Approach Provides Significant Reduction of Cost and Bridge Deck Area As Well As a Pleasant Trail User Experience

John Rohner • *CH2M HILL*

The Truckee River Bridge in Tahoe City, California will provide bypass access around the city and facilitate trail access for bikers and pedestrians along the scenic Truckee River. The design incorporates many unique features to provide a cost effective and aesthetically pleasing solution to carry highway traffic on the bridge and accommodate trail users below. The original planning study completed by others recommended a three-span bridge supported by deep foundations that included complex deck geometry with trails under each of the end spans. A reason for the complex geometry was due to the fact that the bridge had the majority of a roundabout on the west span. It was apparent that any efforts to reduce the length of the bridge would help decease the geometric complexities of the proposed option and decrease the construction costs. A reduction in superstructure depth would also help provide additional vertical clearance for the trails. By understanding all the unique requirements of the project, the planning study layout was revisited, resulting in a bridge solution that was one-fourth the size by area and reducing the anticipated construction cost by over 50 percent. This provided the client with a solution that satisfies all required design codes while reducing the estimated design cost significantly. With a focus on speed of construction, the modified design was also developed with approaches to streamline the structural geometry, simplify the superstructure type, and reduce foundation design requirements. The design features a simply supported main span using precast concrete deck bulb tee girders supported on cellular abutments. The cast in place concrete cellular abutments are innovatively designed to provide a top slab with minimal structural depth to support the roadway above and provide sufficient clearance for the trail below. The bottom slab of the cellular abutment was detailed to remain stable during the design scour and seismic events. The channel side wall of each cellular abutment contains large openings to provide unobstructed views of the river for trail users and provide natural light through the cell. Although torsionally eccentric, the cell was designed to remain elastic during the design seismic event and detailed to yield appropriately during an event that exceeds design levels. This presentation will discuss the iterative approach to transforming a complex preliminary design to an economical and constructible final design. Also highlighted will be the design requirements and challenges as well as the innovative solutions that were successfully implemented during the final design of this bridge. These include the design of spread footing abutments for stability during the extreme scour event, the incorporation of cellular abutments and accelerated construction techniques to minimize project costs, and the seismic design of a torsionally eccentric cellular abutment.

K2 GENERAL SESSION

Renewal of Aging and Deteriorated Reinforced Concrete Bridges with Titanium Alloy Bars

Chris Higgins • *Oregon State University*

Many older reinforced concrete (RC) bridges are identified as deficient in flexure and/or shear when applying modern design standards for their evaluation. The deficiencies most often are due to inadequate amounts of reinforcing steel and/or poor reinforcing details. To prevent the need for expensive replacements it is desirable to extend their service life by strengthening them. Strengthening approaches must be both structurally efficient and cost-effective. Titanium alloy bars offer a new opportunity to strengthen existing bridges that has not previously been investigated, due primarily to the perception of high cost. However, titanium's combination of strength, ductility, durability, and ability to form mechanical anchorages are essential characteristics for effective repair and retrofit applications and are advantageous over competing materials such as steel and fiber-reinforced polymer (FRP) products. Round titanium alloy bars with unique deformation patterns were specially developed for strengthening RC bridge girders. Research using the titanium alloy bars to strengthen RC bridge girders in both flexure and shear was undertaken in the laboratory through full-scale tests. Realistic girder specimens were constructed, instrumented, and tested to failure. The specimens mimicked the in situ materials, loading interactions, and geometry of typical mid-20th century reinforced concrete deck girder bridges that are widely found across the US. Using the findings, the flexural strengthening techniques were applied to a bridge overcrossing of a major interstate highway in Oregon. This first ever application of titanium alloy bars to a reinforced concrete bridge was completed at a 30% cost savings compared to alternative designs. In addition to strengthening bridges for gravity loads, recent research findings demonstrate the ability of titanium alloy bars to retrofit seismically deficient columns thereby transforming them into high-performance seismically resistant members.

Achieving Operational Seismic Performance of Existing Highway Bridges with Ductile Fuse Retrofit

Peter Dusicka • *Portland State University*

Typical reinforced concrete bridges constructed in the 1950s through to the 1970s in the Pacific Northwest were designed and built with minimum seismic considerations. Today, bridge design in Oregon considers dual performance levels; the life-safety performance for a probabilistic 1000 year return earthquake and an additional operational performance level for a full rupture of the Cascadia Subduction Zone. The latter design criteria can govern the seismic design for new bridges and make retrofitting of existing bridges very challenging.

This presentation will summarize a multi-year research effort in utilizing ductile brace fuses to address not just the life-safety criteria, but also the operational design criteria for seismic retrofit of existing highway bridges. The study encompassed feasibility and numerical evaluation of the concept, large scale experiments as well as case studies of 3 different actual bridges in Oregon. The large scale experiments utilized two column bents and investigated two different fuse configurations. These experimental results validated that meeting the operational performance level for an existing bridge is achievable using this technology. The test measurements helped to calibrate numerical models, which were then further utilized to develop the seismic fragility of the retrofitted bridges. Preliminary retrofits were designed for the case study bridges by considering different conventional retrofit measures such as concrete overlay, steel jacketing and concrete in-fill walls as well as considering the ductile brace retrofit. The comparisons highlighted that achieving the operational and life-safety performance with ductile fuses can be not only feasible, but also a cost effective retrofit strategy.

Hence, deploying the ductile brace retrofit through the developed design methodology can significantly enhance the resiliency of the existing bridges in a cost-effective manner and as such, should be part of the designer's toolbox in areas of moderate to high seismicity.