PRACTICAL SOLUTIONS TO BRIDGE ENGINEERING CHALLENGES

Peppermill Hotel

Reno, Nevada

Seminar managed by:

Conference Management
Washington State University

K1 KEYNOTE

I-74 Mississippi River Bridge: A State of the Art Design

Norman McDonald • *Iowa Department of Transportation*

The existing I-74 Mississippi River Bridge connecting Bettendorf, Iowa with Moline, Illinois is a vital component of the transportation corridor in the Quad Cities. The twin suspension bridges, a national historic landmark, will be replaced with dual 795' Steel Basket Handle True Arch bridges consisting of a total of twelve vehicular traffic lanes (eight lanes and four full size shoulders) and a bicycle/pedestrian trail.

The new arch bridges will provide the high degree of elegance that was desired by the community. The design team tackled complex arch design issues such as buckling behavior of the minimally braced arch rib, evaluation of dynamic wind loads, mitigation of wind vibration affects, and a detailed construction analysis of both arch spans. The bicycle/pedestrian trail will be asymmetrically cantilevered off the eastbound arch bridge before converging into a monolithic bridge deck on the girder approach spans.

A structural health monitoring system (SHM) will monitor corrosion, load distribution, and movements. Motorized travelers and an extensive walkway system will provide easy access for inspection and maintenance. In addition to the basket handle arch, other aesthetic features will include an overlook on the arch bicycle/pedestrian trail with a glass oculus, eccentrically intertwined Y-shaped pier columns, and special LED lighting.

In this paper the authors will discuss the unique design challenges and features of the signature structure, highlighted above, such as the arch state-of-the art structural design and analysis, the SHM system, the built-in inspection and maintenance system, and the aesthetic features.

2A ACCELERATED BRIDGE CONSTRUCTION

Utah SR-201 Bridge Slide

Richard Hansen • *Michael Baker International*

The SR-201 over KCC Arthur Mill Railroad project included many design constraints that complicated this bridge slide project. The existing three-span superstructures were replaced with single span superstructures. The existing bents were used as new abutments with new MSE walls constructed behind the existing bents, under the existing end spans. Other complexities included the 61 degree skew, semi-integral abutments supported on seismic isolation bearings, and horizontal/vertical clearance issues during construction due to railroad track alignment and profile. This presentation will cover the design and construction challenges and how the project team successfully navigated these challenges.

ABC Methods for Bridge Replacement on SH-55, North of Cascade (ID)

Leonard Ruminski • *Idaho Transportation Department*

SH-55 is a two-lane major scenic route connecting Boise with US-95 to the North at New Meadows. Both highways provide the only routes contained entirely within the state for carrying commercial and tourist traffic between northern and the southern Idaho. Cascade is a small resort town located 75 miles north of Boise on SH-55. The existing 65 year old, three-span steel girder bridge crossing North Fork Payette River just north of Cascade has been determined as structurally deficient and therefore originally scheduled for replacement in 2017. However recent underwater inspections revealed that exposed steel piles supporting the existing bridge piers through 20-foot river depths are heavily corroded with as much as 50% section loss. The subsequent substructure bridge analysis proved that the deteriorated piles could no longer support heavy truck loads, so the bridge was posted, limiting truck weight and accessibility.

ITD was quickly determined to lift truck traffic restrictions by encapsulating the corroded piles with epoxy filled jackets in 2014 to improve the overall bridge stability. The decision was also made to move up the scheduled bridge replacement to 2015.

In order to minimize impact on traveling public and local businesses, the bridge replacement will have to be done in as short period of time as possible, while maintaining two-way traffic through the construction site at all times. Therefore, the new two-span, 250-foot long concrete bridge was designed and built using Accelerated Bridge Construction (ABC) methods. The superstructure and substructure consists entirely of prefabricated components. The prefabricated components are delivered to the job site and quickly erected. Connections between precast elements are quickly made using high strength, fast curing grout and concrete. Of particular interest is an innovative method of constructing the pier support in a deep river without the use of time consuming and expensive cofferdams. Special attention was also given to the bridge aesthetics, because of its location within a recreational area.

The presentation will show the temporary repairs done to the existing bridge and will focus on the unique bridge replacement approach due to the challenges posed by the tight schedule, traffic handling and difficult access at the construction site. The project also includes slight roadway realignment at both bridge approaches to accommodate staged construction and extensive use of MSE walls. It is scheduled to be completed within 4 months between May and August of this year.

The Lardo Bridge Slide

Brian Byrne • *Lochner*

The Lardo Bridge replacement in the resort town of McCall, Idaho is the first implementation of slide-in-bridge-construction (SIBC) technology of a permanent structure by Idaho Transportation Department (ITD). The use of slide in bridge construction minimized the disruption to SH-55 during the busy summer months and allowed the road to be reopened well before the winter tourist season opened.

While the existing bridge remained open throughout the summer, the replacement structure including the abutment stem wall was constructed to the north of the existing bridge. Permanent piles and the pile caps were installed outside of the footprint of the existing bridge, maximizing the work that could be done before demolition.

Less typical for SIBC, the full abutment stem height and the superstructure were moved together onto the permanent pile caps place after the summer tourist season. This accelerated construction work avoided the forming and concrete pours that would have otherwise had to occur beneath the confines of the existing bridge. The abutments in their permanent locations do not have a flexural connection to the pile caps, avoiding some of the complexity required on other SIBC projects. The bridge is restrained from non-thermal movement through the use of external shear keys, passive soil pressure and friction between the foundations and the abutments.

Once the new 3.5 million pound superstructure and its abutment were ready to be slid, SH-55 was detoured and the existing bridge was demolished. A soil-supported concrete slide slab was installed between the pile caps to create a continuous slide surface for the bridge to move from the temporary shoring to the permanent pile caps. Beam ledges in the permanent pile cap supported the temporary shoring and the slide slab so that differential displacement could be avoided as the bridge slid from its temporary to permanent location.

Anchor blocks for the lateral jacking system were temporarily installed into the pile caps and fabricated steel push blocks were fit onto the north ends of the abutments. Threaded high-strength bars were placed on both abutment faces and extended from the push block to the anchor blocks. Seventy-five ton center-hole jacks at the push block moved the bridge in 7 inch increments on top of the slide pads to its permanent location. Slide pads were continuously reset in front of the abutments as they progressed their way across. The arrangement of the push blocks and the jack manifold system allowed for alignment adjustments. Engaging one set of jacks at one abutment rather than all four rotated the bridge to correct its path.

This presentation will provide a clear understanding of the approach used for ITD's first use of slide-in-bridge-construction, the atypical slide of the abutments with the superstructure, and the connection details that resulted from this construction method.

2B BRIDGE FOUNDATION SEISMIC DESIGN

Modeling and Design of the Gilman Drive Overcrossing Foundations

Garrett Dekker • *Moffatt & Nichol*

The University of California, San Diego will soon construct a bridge to better connect the east and west sides of campus, which is bisected by the I-5 Freeway. The new structure will be a 406 ft long concrete arch bridge. The 62 ft wide bridge is designed to carry three lanes of vehicular traffic and a sidewalk in each direction. The total length of the bridge is comprised of three spans: back spans of 115 ft and 120 ft and a main span of 172 ft. The superstructure is supported by four arch legs, which frame into the superstructure at the crown and into a single large pile cap on each side of the freeway. The arch spans 315 ft along the spring line, and rises 36 ft at the crown. Each footing is supported on 48 micropiles which are approximately 60 ft long. To reduce the thrust on the foundations, an inclined strut connects the ends of the bridge to the pile caps.

Competent rock is present at shallow depth below grade and initially spread footings were proposed to anchor the thrust of the arch. However, geotechnical investigations revealed that while the weathered sandstone layers had enough strength, they lacked sufficient stiffness to reliably resist the thrust of the arch without significant outward movement. Therefore, micropiles were identified as an efficient way to transfer the high arch loads to stronger rock formations below the footing, while preventing the base of the arch legs from moving under the high loads. Micropiles were also desirable from the standpoint that they could be installed at steep angles, which is desirable for resisting the inclined thrusting action of an arch.

The majority of the structure was modeled in Bentley's RM Bridge, an advanced computer software program used for the design and analysis of bridges. However, the interaction of forces between the arch legs, struts and micropiles necessitated specific modeling of the foundation components and ongoing collaboration between the structural designer and the geotechnical engineer. Foundation forces from RM Bridge, including force couples derived from the two arch legs, were exported to a SAP2000 structural shell model, where the footing and each of the 48 micropiles were individually discretized. The resulting balance of forces led to iterations with regard to the micropile inclination angle and the placement of the strut, intended to help reduce the thrust acting on the foundations. A pushover analysis was also performed in the foundation model to verify the ductile response of the micropiles under seismic forces.

The presentation will describe the specific geological conditions and other factors that led to the use of micropiles. The structural behavior of the bridge, and specifically the decision to include struts, will be discussed accompanied by the designer's methodology for capturing the flow of forces into the foundation. Micropile constructability and design, site specific and otherwise, will similarly be presented. Lastly, foundation modeling will be outlined along with the various outputs and iterations which influenced the final form of the bridge.

Seismic Design of Adjacent Rail Bridges in Deep Liquefiable Soils

Kelly Burnell • *Kleinfelder*
Ebrahim Amirihormozaki • *Kleinfelder*

A double-track heavy rail replacement bridge and a new double-track light rail transit (LRT) bridge have been designed to cross the San Diego River in San Diego California. This presentation will cover some of the seismic challenges and solutions developed in designing these structures.

The heavy rail and LRT bridges are part of the Los Angeles-San Diego-San Luis Obispo Rail (LOSSAN) corridor upgrades and the Mid-Coast Corridor LRT Project respectively and will both be constructed as part of the same Construction Manager General Contractor (CMGC) Contract. A horizontal clearance of only 4'-6" separates the two bridges, which require phased construction within a 100-foot right-of-way. Close coordination and a consistent approach for the seismic behavior of the adjacent structures have been crucial.

Within the San Diego River floodplain, liquefiable soils extend from the ground surface down approximately 50 feet. To address the liquefaction hazard, post-installed ground improvement to a depth of 90 feet below the existing ground surface was initially proposed as mitigation. The required volume of ground improvement was extensive and expensive. It was determined through cooperation with the agency, the CMGC contractor and the design team, to implement construction with permanent steel casing. The design team investigated the possibility of taking advantage of its added stiffness and strength from the casing to eliminate the soil improvement. The permanent casing is expected to provide a savings of several million dollars for the project. Using a consistent approach between the structures required the cased shaft to meet varied performance based seismic criteria (AREMA and Caltrans) for the bridges.

The heavy rail bridge will be a steel, through-girder bridge with 11' deep girders. The design team developed a simplified method of checking the lateral seismic force transfer path through the framing system and confirmed this method using a 3D finite element model. The simplified method of evaluating the resisting system will be presented as well as the key detailing considerations of the through girder bridge.

Two Dimensional Seismic Site Response Analysis for a New Bridge in a Subduction Zone Environment

Zia Zafir • *Kleinfelder*

Smith River Bridge replacement project involves construction of a new about 1,000 feet long four-span hunched box girder bridge with a continuous deck isolated by triple frictional pendulum (TFP) bearings. The bridge will replace an existing bridge supported by two abutments and 17 piers. The site is located in northwest California near Crescent City in an active seismic region. The seismic environment around the project area is dominated by the Cascadia Subduction Zone (CSZ). Although some shallow crustal faults are located near the bridge site, the seismic hazards for this bridge are governed by the CSZ. Based on the available subsurface information, geotechnical/geologic conditions vary significantly along the length of the bridge, ranging from shallow metamorphic bedrock north of the river, to deep alluvium consisting of saturated sand, silt, gravel and cobbles south of the river. Depth of alluvium at the south side extends to about 130 to 150 feet below the ground surface. In order to perform three-dimensional (3D) soil-structure-interaction analysis of the bridge and foundation systems, three-component time histories at 10-foot vertical intervals along the foundation length at each pier and abutment location are needed. Due to the variation in geotechnical/geologic conditions along the longitudinal direction of the bridge, a two-dimensional (2D) seismic site response analysis is required to develop three-component time histories. The 2D seismic site response analyses were performed using computer program QUAD4M. Response spectrum at the bedrock level was developed using recommended procedures by California Department of Transportation (Caltrans) and using probabilistic and deterministic seismic hazard analysis (PSHA and DSHA). Seven sets (each set containing two orthogonal horizontal and one vertical motions) of spectrally matched time histories representing subduction zone environment were developed and used in the 2D seismic site response. In addition, computer program DEEPSOIL was used to perform one-dimensional (1D) seismic site response analyses to model site response in the transverse direction of the bridge. Results of QUAD4M were calibrated against the DEEPSOIL results in the transverse direction of the bridge. This presentation will present the results of ground motion hazard analyses, deaggregation analyses, selection and spectrally matching seven sets of time histories, and results of 1D and 2D site response analysis. Results of seismic site response show significant variation in site response along the longitudinal direction which can't be captured in a 1D site response.

2C BRIDGE DESIGN CONSIDERATIONS

New Design Provisions for Lightweight Concrete in Bridges

Reid Castrodale • *Expanded Shale Clay and Slate Institute*

The use of structural lightweight concrete has been mentioned in bridge design specifications in the US since at least 1973, and has been in the ACI Building Code longer than that. The design provisions for lightweight concrete in the AASHTO LRFD Bridge Design Specifications are essentially the same as were in the Standard Specifications.

In April 2015, a major revision to the AASHTO LRFD Bridge Design Specifications was approved. In the prior year, the equation for the modulus of elasticity of concrete was revised to better reflect the behavior of lightweight and high strength concrete. This presentation will present these changes and discuss the impact that they will have on bridge designs using lightweight concrete.

FHWA Slide-In Bridge Construction Cost Estimation Tool

AJ Yates • *Michael Baker International*

Michael Baker International and Leidos, Inc. developed a Slide-In Bridge Construction (SIBC) Cost Estimation Tool for the Federal Highway Administration (FHWA) as part of the Every Day Counts Initiative to advance innovative techniques. SIBC is a relatively new, innovative, and underutilized technology. Cost estimation of such new and innovative construction techniques can be challenging and uncertain. Our team developed an Excel spreadsheet with an accompanying guide manual to assist agencies in evaluating traditional construction alternatives with SIBC alternatives. The tool also aids in estimating a slide construction cost bid item. The tool was designed as an extension of the SIBC Implementation Guide which Michael Baker International developed with the Utah Department of Transportation for FHWA.

The SIBC Cost Estimation Tool implements historical cost data collected from 29 completed SIBC projects across the country. The use of historical cost data makes the tool especially useful as it provides a frame of reference for agencies to compare their upcoming project with completed projects across the county and their associated costs. The tool uses a straightforward and easily understood approach to increase confidence in using the SIBC technology.

This presentation will describe the development process of the SIBC Cost Estimation Tool as well as its function. It will discuss the challenges of creating a tool which can be used by most agencies, contractors, and engineers while working with a limited sample size of historical data. The presentation will explain the data collection process as well as the analysis of the data in order to establish an estimation methodology. The components used in the tool will be discussed including the factors which increase or decrease cost, additional construction costs affected by site constraints and constructability, and additional project costs such as administrative costs and incentives or disincentives. The presentation will conclude with examples of how the tool can be used on real world projects.

The Future of Bridge Design, Modeling and Analysis: 3D Modeling from Design to Decommission

Barbara Day • *Bentley Systems*

Design, modeling and analysis are keys to the success of bridge projects. A next generation of bridge modeling software requires that it be purpose-built for bridge designers and consultants who need to create, augment, maintain, and document a wide variety of bridge information throughout the lifecycle of the project. Sharing information in an information-rich 3D model increases data quality, collaboration and asset management, and reduces overall costs for the entire ecosystem involved. Intelligent 3D models are key to accelerated project delivery and information mobility. This presentation will provide an overview of how a powerful new software interoperates with civil design and collaboration tools, providing engineers with a fresh approach to bridge projects of all sizes.

2D BRIDGE REHABILITATION

Rehabilitation Of Tacoma S Avenue Bridge

Kash Nikzad • *TranTech Engineering, LLC*
Vietanh Phung • *TranTech Engineering, LLC*

This paper describes the rehabilitation of the Tacoma S. Avenue Bridge. The Tacoma S. Avenue Bridge was constructed in the early 1930s. The bridge is 333 feet long and consists of 6 spans. Superstructure is concrete deck on steel plate girders. The substructure consists of steel piers and concrete abutments.

Load rating of the Bridge (2010) indicated that the bridge needed a posting. The bridge traffic is currently limited because of corrosion and deterioration of the bridge structure. The current rehabilitation project included repairs to the bridge superstructure, deck, and abutments. The project also included a post-rehabilitation seismic evaluation of the bridge.

Due to the traffic requirements, the roadway width is increased by 18 feet (9 feet on each side). These 9 feet wide cantilevers are supported along the exterior plate girder of the bridge. The forces associated with this cantilever system is carried with additional new cross frames to interior girders.

Due to the weight considerations and its associated seismic forces it has been decided that the new concrete deck to be constructed with light weight concrete and to be made composite with the steel girders.

The following topics will be described in further detail associated with this rehabilitation project:

1. Use of lightweight concrete to mitigate the effect of seismic forces.
2. Making the cross frames as primary elements to transfer the exterior cantilever sidewalk forces to interior parts.
3. Columns Strengthening

Replacement of Trunnion Bearing, 92nd Street Bascule Bridge, Chicago, Illinois

Paul Bandlow • *Stafford Bandlow Engineering, Inc.*

The Chicago Department of Transportation's (CDOT) 92nd Street Bridge over the Calumet River is a Chicago Style Double Leaf Trunnion Bascule built in 1914 and was last rehabilitated in 1992. The span opens approximately 3,000 times a year primarily for commercial vessels and is therefore critical to Chicago's infrastructure and commerce. Bi-annual inspections of the bridge's mechanical system have noted the progressive deterioration of the bridge's south leaf east trunnion bearing. Wear had progressed to the point that the trunnion shaft nearly wore through the bronze bushing and into the trunnion casting. The authors lead the design team that provided both design and construction support services for this interesting project that evolved from a fast track project into an emergency project that was in part directed by the design team. The paper will discuss the scope of the initial design work, the probable cause of the unusual wear, fatigue and stress analysis, inspection that changed the direction of the project, worked required to jack and secure the span in the open position, removal of the trunnion bearing, in-place machining of the trunnion shaft and procedures taken to ensure proper alignment and fit of the trunnion into the rehabilitated trunnion bearing assembly.

Slausen Avenue Bridge Over San Gabriel River

Bob Fish • *AECOM Transportation*

This project was to accommodate a third rail line within the BNSF Railroad corridor for Caltrans commuter trains. The tracks are at a very high skew of 69 degrees from perpendicular to the bridge. Major modification to two piers was required. The first design proposed by others was determined to be a high construction risk due to the complexity of the details during our constructability review. AECOM demonstrated that an alternative design could reduce the construction cost by nearly 50% (about $3.2 million), while also avoiding risk. The client agreed, and Caltrans approved the funding.

The modifications required replacing a steel beam bent cap with a much longer outrigger steel beam supported on seismic isolation bearings at Pier 6 and designing an all new concrete pier wall with a 32 foot cantilevered concrete cap beam over the tracks, with soil tie-down anchors on the opposite side. The project was constructed with very minimal issues and is now open.

This structure is under the review jurisdiction of the County of Los Angeles, who required that the new piers also be designed for seismic induced lateral spreading after final PS&E had been submitted. AECOM quickly developed the loading and analysis criteria, and was able to demonstrate that the design did meet the newly required load condition. AECOM also supported the client during pre-bid, was a trusted by the client to serve as a member of the contractor selection panel and was heavily involved in construction support.

3A ACCELERATED BRIDGE CONSTRUCTION

Accelerated Bridge Construction in Alaska

Leslie Daugherty • *Alaska DOT&PF*

The presentation will discuss how the Alaska Department of Transportation & Public Facilities (DOT&PF) has used various types of accelerated bridge construction (ABC) approaches since the 1970s, but also faces practical limitations to expanding ABC use. One type of ABC approach, the use of prefabricated bridge elements and systems (PBES), has been a time-tested asset to projects. DOT&PF advocates use of PBES due to added benefits beyond the speed of construction. However, the State's high seismic regions limit use of some precast components until more research or design guidance is available. In response to user feedback, an FHWA Experimental Features project for polyester concrete bridge approach slabs is also ongoing to minimize traffic delays during construction. Various types of accelerated project delivery methods (APDM) have also been implemented, but with mixed results. The lessons learned from these nontraditional contracting methods will be discussed, as well as the role cost plays in selecting ABC project components in Alaska.

Alaskan Way Viaduct Replacement Program - Pre-Cast Concrete Elements for ABC Construction

Tim Moore • *Washington State DOT*

This $3.1B Viaduct Replacement Program has successfully completed a number of projects that are serving one of the two main transportation corridors in Seattle, WA. This presentation will explore the utilization of precast concrete elements in a variety of items; prestressed girders, tubs, flat slabs and even universally tapered tunnel liner rings. Pre-cast concrete is the staple ingredient to match the goals and objectives of Accelerated Bridge Construction, ABC.

The program overview features up to 205' single-stick prestressed girders, curved prestressed post-tensioned tubs, transversely pre-tensioned flat slabs that are joined with longitudinal concentric post-tensioning and over 14,000 high-strength concrete tunnel liner panels.

Innovative Bridge Designs for Rapid Renewal, SHRP2 R04, Lessons Learned

Finn Hubbard • *Fish & Associates Inc.*

The SHRP2 project on Rapid Renewal of Bridges (Innovative Bridge Designs for Rapid Renewal, R04) is coming to a successful close and has produced several positive outcomes and products that can be used by all transportation agencies. The first was a "Tool Kit" with information on how a transportation agency might approach the process of replacing an existing bridge in a greatly accelerated manner. This process includes prefabricating most of the bridge off-site or in some cases sliding the bridge in from the side with a roadway closure of less than one day. Best practices from around the country were gathered in the Tool Kit and the various methods were tested by eight "lead adopter" transportation agencies during 2014 and 2015. Three showcases were held by the FHWA, AASHTO, and the lead adopter states along with a Peer-to-Peer exchange in California in May 2015. The showcases gave the lead adopter state a chance to highlight its bridge project and the many lessons learned when applying the Innovative Bridge Designs Tool Kit. The Peer-to- Peer exchange gathered lessons learned from 13 western states with an opportunity to share these lessons with each other.

This presentation is a compilation of the lessons learned during the SHRP2 Innovative Bridge Designs project with an emphasis on the experiences and observations of the transportation agencies as they move into the accelerated bridge construction world.

3B BRIDGE DESIGN AND CONSTRUCTION

Design of the Gilman Drive Bridge over Interstate 5 at the University of California, San Diego

Gernot Kumar • *Moffatt & Nichol*
Tony Sanchez • *Moffatt & Nichol*

The University of California, San Diego (UCSD); a world renowned university with a reputation for innovative and state-of-the-art research in the field of Structural Engineering, in conjunction with Caltrans has recently administered the construction of the Gilman Drive Overcrossing Interstate 5 (I-5). The proposed project is intended to improve mobility between the East and West campuses, as well complete the master campus loop plan for its local facility users. Currently, only one structure to the North connects the campus, however this bridge is slated to be removed in the near future and replaced with a widened Direct Access Ramp (DAR) to promote mobility throughout the region and campus. In addition, the Gilman Drive Overcrossing sets a visual precedence and signature gateway to the I-5 North Coast Corridor, a comprehensive program to improve approximately 27-miles of I-5.

The selected structure type, a slender twin-leg arch and box-girder superstructure was the result of collaboration between UCSD, Caltrans, Moffatt & Nichol (Engineer of Record), and Safdie Rabines Architects (Structure Architects). The total bridge length is 406-ft 6-in, with a 172-ft main span, and 115-ft and 120-ft back spans. At 62-ft wide, the bridge carries three lanes of traffic and a total of 16-ft of sidewalk, 10-ft to the North and 6-ft to the South. The prestressed, box girder superstructure, a staple of California bridge construction, is supported by the four arch legs, a pair on either side framing into the superstructure into a stacked-cell arrangement. The twin arch legs are founded on a single, large arch abutment. Each arch abutment is founded on 48 inclined micropiles, each nearly 60-ft long. In addition to the single large arch abutment and micropiles, it was determined during the preliminary design stage that an inclined strut would be needed to link the arch abutment to the superstructure end-diaphragm in order to reduce the thrust and thus improve micropile-foundation behavior and capacities.

The bridge was modeled in Bentley's RM Bridge software due to its unparalleled ability to capture time dependent effects and staged construction analysis. In addition, the software's capabilities were paramount in allowing the design team to assemble complex cross sectional members into a unified structural model with the added functionality to iterate upon those shapes and sections as the design progressed from Preliminary Engineering through Final Design. The low profile arch and high thrust forces at the foundations required multiple analysis model iterations to achieve a desired thrust reduction of over 25%. The slender arch legs, each a hollow box section, created an additional complexity at the location where the arch frames into the box-girder bridge superstructure. The arch legs framed into the box girder in such a way that stacked exterior box girder cells, while maintaining a uniform, single center cell in the superstructure. RM Bridge demonstrated its ability to accurately analyze carefully modeled complex cross sections with varying geometry in three directions.

The presentation will describe unique design considerations, seismic concerns and design approach, and other factors which resulted in the Caltrans approved design. The structural behavior of the bridge and arch legs, their effect on the foundation and strut will also be discussed, along with the designer's methodology for capturing the flow of forces into the elegant form it has become.

Hybrid Spliced Girder Concept to Solve Bridge Constructability Challenges

Sami Megally • *Kleinfelder*

Cast-In-Place (CIP) bridges are economical and perform well seismically in California. However, congested urban interchanges bridge construction, especially widening, presents significant technical challenges that are difficult to overcome using conventional CIP construction. These challenges include geometric constraints, traffic maintenance, accelerated construction schedule, seismic design, and cost constraints. An innovative approach to meet these challenges is the use of precast concrete girders spliced with CIP girders. This innovative "Hybrid" construction concept has been developed and used in bridge widening projects. This presentation will focus on the potential advantages and disadvantages of this bridge type using two recent project examples as case studies.

The first case study is the design-build HOV widening of State-Route 22 over Interstate 5 in Orange County, California (SR-22/I-5 Separation). At this location, SR-22 crosses 17 lanes of I-5 traffic, on a curved and skewed alignment. Because of the curved alignment and required superelevation, the vertical clearance is reduced at the edge of the widened structure, which would allow almost no room for falsework required for conventional CIP construction. The interchange connecting I-5 with SR-22 and SR-57 is widely known as the "Orange Crush," due to the reputation this transportation hub has for severe traffic congestion. Therefore, maintenance of traffic during construction was a significant concern especially on I-5, where only evening closures of short duration were permitted. In addition to geometric and traffic constraints, the structural response characteristics of the widened structure and the existing structure must be compatible to ensure adequate performance and durability. To meet all design and aesthetics requirements for this project, precast curved bathtub girders were used for the critical span over the I-5, where existing vertical clearance precludes conventional falsework. The remaining spans were constructed using CIP tub girders. Technical challenges of this project included: analysis of time-dependent effects throughout all construction stages, the differential live-load deflections between the existing and widening structures, and the erection method of the heavy non-symmetric curved bathtub girders. This project is believed to be the first one in California to use precast curved bathtub spliced girders.

A second case study of hybrid spliced girder construction is widening of the existing Interstate 15 over Felicita Road in San Diego County, California. The existing structure consists of CIP multi-cell box section with three spans. The middle span is 108 ft long and spans Felicita Road. Due to the cross slope of the existing bridge and the existing profile of Felicita Road, there was not sufficient temporary or permanent vertical clearance for the new structure. If conventional CIP construction was to be used, the superstructure would have been either cast high and lowered, or the existing grade of Felicita Road lowered. The first option had construction risks given the structure's continuous spans and the second option would affect several existing utilities. The hybrid spliced girder concept was the perfect solution to this project. Precast box girders were used to span the portion of the bridge over the existing road and the remaining portion constructed using CIP concrete. The precast and CIP girders were spliced by means of post-tensioning. Technical challenges of this project included the shallow superstructure depth, and differential deflections between the widening and existing structures. Detailed time-dependent analysis was required to ensure that the required camber profile is obtained, deflections under live loads are acceptable, and the stresses are within the allowable limits throughout all stages of construction.

Design of a Modern Cable Stayed Bridge in a High Seismic Zone

Patrick Montemerlo • *David Evans & Associates, Inc.*

Bridges are an integral part of our transportation system. The average age of a bridge in the United States is 42 years old, but some are much older. The Puyallup River Bridge in Tacoma, Washington is more than 90 years old and is both functionally and structurally deficient. Due to the condition of the existing bridge the City of Tacoma began an estimated $100 million multi-phase bridge replacement program. The replacement structure will feature a state of the art signature cable-stayed bridge that will be the first cable stayed bridge constructed in the state of Washington in the 21st Century.

A number of factors that included profile and alignment constraints, construction speed and the need to cross six active rail lines all drove the selection of this unique signature cable-stayed bridge with two 400-foot-long main spans. This paper will detail how this signature cable-stayed bridge was designed to meet modern high seismic zone analysis and design requirements. Also discussed will be some of the unique modern elements of this new structure that will include a precast/post-tensioned concrete main span superstructure and modern stay cable system, along with the construction specifications developed to minimize project risk while still allowing cost saving and construction innovations for the builder. The paper will conclude with a summary of how the team succeeded and lessons learned during this phase of the project.

3C BRIDGE CONSTRUCTION

Girder Stability in Erection and Demolition

Michael Garlich • *Collins Engineers, Inc.*

The recent collapse of a bridge in Cincinnati while under demolition and girder buckling during bridge erection in Edmonton, Canada, again demonstrate the need to consider stability during both erection and demolition. Girder instability may arise from various causes such as roll instability, lateral torsional buckling, or system buckling of two (or more) girders interconnected by cross-frames or diaphragms. In addition, changing loading conditions as erection or demolition progresses can alter member behavior.

Members must be stable at all stages of erection. This requires a stage-by-stage analysis, addressing loading and support condition variation. Critical erection stages include girder lifting, setting the first girder and temporary bracing, placing the second girder segment and cross bracing, and often other stages. It is critical that girders be restrained from twist at supports in order for the flexure equations to be valid.

Loading conditions during erection reflect the probability of occurrence; thus, wind loads may be adjusted based on expected work duration. Girders under erection create an open assembly which will experience different drag coefficients than the finished bridge. When load duration factors are used to adjust loads to less than "permanent" values, contingencies must be provided to account for unexpected occurrences. Loads and analysis parameters must also address erection and fabrication/production tolerances. As an example, concrete girder roll stability during girder setting must consider actual sweep, camber, and bearing pad tolerances.

Over the past several years, additional guidance or engineering for erection and demolition has been made available from PCI, the AASHTO/NSBA collaborative, and most recently, FHWA in conjunction with NHI. Much of the needed engineering calculations can be prepared using "hand" methods, spread sheets, or similar methods. The use of eigenvalue buckling analysis can be readily accomplished with many structural analysis programs and is encouraged for other than routine projects.

In addition to the engineering considerations, field staff should be aware of indications of potential instability or overload so that remedial measures can be initiated if needed.

Project Risk Management on the New San Francisco Oakland Bay Bridge

Richard Foley • *California Department of Transportation*

In 2005 the Legislature of the State of California enacted Assembly Bill #144 to provide funding for the Self-Anchored Suspension Bridge portion of new East Span of the San Francisco Oakland Bay Bridge. This project constructed the signature span of the $6 Billion mega-project and was the largest construction contract awarded by the California Department of Transportation (Caltrans). A comprehensive Program Risk Management Program was also required by this law. This presentation examines the process of enhancing our Risk Management Program to comply with the law and provides examples of how this effort allowed the Department to make informed decisions.

Response to Falsework Collapse During Bridge Construction

Mark Creveling • *Kleinfelder*
Craig Shannon • *Kleinfelder*

This presentation will discuss the material properties of structural lightweight concrete that are of importance in the design and performance of bridges. The properties discussed will include modulus of elasticity, splitting tensile strength, compressive strength, creep and shrinkage. The impact of these material properties on design of bridge elements will also be presented, including recent changes to the AASHTO LRFD related to lightweight concrete.

3D BRIDGE REHABILITATION

In-Service Replacement of Box Girder Bottom Slab SDOT Bridge 5/537S Span 11

Craig Boone • *WSDOT*

Bridge 5/537S is a heavily traveled structure that carries traffic from West Seattle to northbound Interstate-5. This bridge was originally constructed in 1966 and is generally in good condition. In recent years WSDOT bridge inspectors had identified poor quality concrete in the box girder bottom slab of span 11. The condition of the concrete was so poor in places that it could be easily removed with hand tools. In late 2011 WSDOT began looking at options for repairing or replacing the span. Given the high traffic volumes and lack of alternate routes, there was a strong desire to minimize the bridge closure time. WSDOT developed plans to replace the bottom slab while maintaining traffic on the bridge. In early 2013 the bottom slab was replaced successfully with only a couple days of bridge closure. This presentation will discuss the methods and challenges of completing this innovative bridge rehabilitation project.

Bridge Deck Replacement on Precast Concrete Bulb-T Girders with Sacrificial Flange Technique

Tanarat Potisuk • *ODOT*

This presentation will highlight a complete deck replacement project showing the possibility for a full replacement of a reinforced concrete (RC) deck on a precast-prestressed concrete deck-girder bridge. Lower Perry Bridge (Br.# 19230) is located near La Grande, OR on I-84 having an ADT of 5202 with a truck volume of 42%. The bridge is situated on a mild horizontal curve with a total length of 426.5 ft including 3 spans made simple for dead loads and continuous for live loads. The longest span length is 154 ft. In 2003, a decision was made to construct the bridge with a reversing 2% superelevation on the westbound structure for drainage purposes. Due to several truck toppling accidents at the bridge, in 2013, ODOT decided to replace the 12-year old deck with a proper designed deck with a superelevation, varying between 2 to 5%.

When designing a bridge in a location, where it is prone to have a complete deck replacement in the future, steel girders are often chosen over precast-prestressed concrete girders due to easier deck replacement construction. Precast concrete girders are susceptible to get damaged during deck removal. For this project, the as-designed plan used a traditional concept to cut the diaphragms; remove the concrete deck, while preserving girder flanges; jack the girders to set elevations; and construct new diaphragms and a RC deck. These construction stages are possible, but involved risks during construction, especially girder instability due to the girders' size and length. The contractor team proposed a construction alternative to reduce the risks by cutting the RC deck including the girder flanges and extending the girder webs to support a new RC deck at the set elevations. As a result, the girders were left in place at all time during the construction. The proposed construction procedure provided safe construction and was done quickly. Analysis verification and construction of the deck replacement method will be presented including lessons learned. This project shows that the construction technique can address the deck replacement concerns during a type, size and location (TS&L) selection process and can be used for replacing other deteriorated bridge decks supported by precast concrete girders.

Accelerated Bridge Construction, Rehabilitation of the I-280 in San Francisco

Ric Maggenti • *Caltrans*

Ageing highway facilities in need of repair or rehabilitation need be done quickly and be long lasting so as to minimize disruptions to a local economy's infrastructure. The objective is to get in, get out, and stay out. Interstate 280 facilitates traffic in and out of downtown San Francisco. At the northern end of I-280 a viaduct consists of a conventionally reinforced box girder bridge built in 1964. Hinges of this viaduct, formed at the overlap of two frames each consisting of multiple spans supported continually on columns 30-50 feet tall, were in need of rehabilitation as they were continuously disintegrating. Two options were evaluated. One was to do the repairs in stages keeping a portion of the viaduct operational to traffic. This would mean interfering with traffic patterns continuously for six months. The second option was to completely close down the freeway and do the repair all at once. The second option was chosen. Temporary supports on both sides of the hinge were constructed and the viaduct was closed to traffic. The repair and rehabilitation consisted of demolishing the existing hinge and 25-30 feet of structural box girders and reconstructing to current Caltrans earthquake standards. Four hinges and adjacent box girder were reconstructed over three separate three-day holiday weekends. Each weekend consisted of a work window of approximately 100 straight hours requiring careful planning. The closures commenced one day before the three-day weekend. Scheduling, logistics, quality control measures, inspections, and selection of materials were paramount to success. Concrete design, mixing, batching and placement technique were significant .

4A ACCELERATED BRIDGE CONSTRUCTION

Accelerated Bridge Construction of the West Humbug Creek Bridge

Jason Kelly • *OBEC Consulting Engineers*

The existing West Humbug Creek Bridge is located on the heavily traveled US 26, which connects Portland to the Oregon coast. OBEC investigated several traffic staging alternatives, considering site constraints, traffic delays, and cost, to determine the best approach. Final selection of ABC required close coordination with ODOT Region 2 and Motor Carrier Transportation Division, as well as careful analysis of design impacts and construction cost and duration.

The summer in-water work window coincided with the peak tourist season. These two constraints led the design team to implement a hybrid ABC method: two stages of rapid construction using precast structural elements. The bridge replacement was completed in eight weeks while keeping two lanes of traffic open every weekend. Specific precast elements include a match-cast post-tensioned deck panel system, prestressed girders and pile caps.

The presentation will focus on the design process, detailing the accelerated construction elements and construction.

Prefabricated Bridge Elements and Systems for Accelerated Bridge Construction

Greg Banks • *BergerABAM*

The Boeing Company is the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems. Why would this American multinational corporation use ABC to replace a bridge? Such companies have a tradition of leadership and innovation and depend on profits to sustain their operations, and they are learning that ABC can help them achieve their goals. This presentation features the Boeing North Bridge in Renton, Washington. The bridge, originally constructed in 1940 and lengthened in 1969, was recently replaced with a three-span, 245-ft-long prefabricated bridge. The new bridge consists of steel girders, full-depth precast deck panels with ultra-high-performance concrete closure joints, and seismic-resisting precast concrete cap-and-column supports. The presentation discusses the project's construction and environmental constraints, and the design and construction details that were used to achieve project success.

Seattle's Not-So-Boring SR 99 Bored Tunnel Project

Tim Moore • *WSDOT*

In summer 2013, the world's largest-diameter tunneling machine, named Bertha, began a historic journey beneath downtown Seattle. Its purpose: dig a tunnel to replace the SR 99 Alaskan Way Viaduct, a double-deck highway that has spanned the downtown waterfront for more than 60 years. This $3.1B Viaduct Replacement Program has successfully completed a number of projects that are serving Seattle. The main tunnel contract, however, has experienced significant challenges.

After ~1,000 feet of tunneling (10% of the tunnel drive), increased temperature readings in the tunneling machine led the contractor to stop mining. The contractor is replacing the main bearing and associated bearing seal systems. The cutterhead drive unit is also being reinforced with 100 tons of additional structural steel.

This presentation will provide an overview of the SR 99 Tunnel Project, a description of the structural engineering aspects of the south and north cut-and-cover tunnel approaches, the two ventilation/operations buildings and the double-deck roadway within the bored tunnel. In addition, major heavy civil construction has become necessary to retrieve and repair the tunneling machine. A look at the tunneling machine access shaft, heavy lift movable gantry and a review of machine components and the repair will be presented.

4B BRIDGE DURABILITY AND MATERIALS

Use of Grade 80 Reinforcement in Oregon

Craig Shike • *Oregon Department of Transportation*

In recent years, higher strength reinforcement has become commercially available on the market. AASHTO Bridge Design Specifications now allows higher strength rebar up to 100 ksi to be used in bridge design as prescribed in the 6th edition with 2013 interim revisions. ASTM A 706, Grade 80 rebar has been used in drilled shafts and bridge deck for several projects in Oregon. Grade 80 rebar provides a 33% strength advantage, but only has a cost premium of 8-12% over Grade 60. In addition to the possible cost saving due to the use of a lower volume, use of high strength bars in bridge elements can reduce bar congestion and construction time as well as achieve better concrete placement. This paper will discuss Oregon's evaluation of both Grade 80 and Grade 100 rebar in bridge applications such as decks, crossbeams, and drilled shafts. Recommendations will be provided concerning when use of high-strength rebar can be beneficial. Potential cost savings for Oregon will be presented.

Durability Design of Bridges Specified Service Life

Mike Bartholomew • *CH2M HILL*

The design of bridges has historically focused on the strength aspects of structural engineering – determining loads and forces applied to a structure, then selecting materials and configuring structural components to resist the stresses created from the loads. While that is an extremely important part of the design, it only accomplishes part of what is necessary to allow a structure to remain in use for a long period of time. When a structure nears the end of its useful life, it does so primarily because the material components have begun to deteriorate, not from increased loads that the structure must resist, but due to a breakdown of the materials (steel corroding, concrete cracking, and spalling, etc.) from the environmental conditions they are experiencing. Structures along our sea coast and in northern climates where de-icing salts are used on the roads and bridge decks are the most harshly exposed and have sustained the most damage and deterioration.

Recently, there has been a significant amount of research performed in the study of how materials (particularly reinforced concrete) deteriorate with time. We can now fairly accurately predict how long it takes for chlorides from seawater and de-icing salt to penetrate from the surface of concrete down to the reinforcing steel level. When the concentration of chlorides reaches a certain magnitude at the reinforcing steel, corrosion begins. This has led to new engineering solutions to decrease the rate of deterioration and thus increase the expected life of structures. Engineering design to account for the environmental conditions a structure is exposed to, is the basis for Service Life or Durability Design of structures. This deterioration method and others are all documented in a European standard, fib Bulletin 34 – Model Code for Service Life Design, published in 2006, and being implemented around the globe.

The concept of Service Life Design is new in the US and has not generally been implemented in the design of structures. The AASHTO LRFD Bridge Design Code is silent on the topic. Several large design/build projects have included the concept of Service Life Design in the project scope – most notably, the Tappan Zee and Goethals Bridges in New York, the Ohio River Bridges in Louisville, and Gerald Desmond in San Diego.

The partnership of AASHTO, FHWA and TRB, through the Strategic Highway Research Program (SHRP2), has funded and completed a research project on this topic, R19A, "Service Life Design for Bridges". A SHRP2 Implementation Action Program (IAP) is currently underway to help promote the use of service life design in 5 agency Departments of Transportation. This work is supported by AASHTO Technical Committee T-9 – Bridge Preservation.

This presentation will discuss the development of a critical and highly anticipated technology and report on the work underway on the SHRP2 IAP.

Durability of Lightweight Concrete for Bridges

Reid Castrodale • *Expanded Shale Clay and Slate Institute*

Many engineers are reluctant to use lightweight concrete in bridge construction because they are concerned about the durability of lightweight concrete exposed to weather and traffic conditions experienced by bridges. They expect that the apparently porous lightweight aggregate could not provide durability that is comparable with normal weight concrete. However, laboratory and field experience demonstrate that lightweight concrete can provide excellent durability for bridge decks.

This presentation will begin by discussing the factors that contribute to making the durability of bridge decks constructed using lightweight concrete equal to or better than normal weight concrete. These include internal curing, elastic compatibility of the lightweight aggregate with the paste, a lower modulus of elasticity, and a lower coefficient of thermal expansion. Data from research as well as test data and experience from actual projects will be used to demonstrate the satisfactory durability of lightweight concrete bridge decks. A few bridges will be discussed which demonstrate the good long-term performance of lightweight concrete.

4C BRIDGE CONSTRUCTION

Lateral Slide of a Historic Warren Truss In Washington State

Kevin Dusenberry • *Jacobs*

To shorten construction time and minimize construction costs, an existing truss was moved to become a detour bridge. Moving of the bridge allowed for use of the existing roadway alignment and infrastructure for the permanent construction. Preserving the existing alignment eliminated the need for retaining walls, barrier and sidewalk modifications to the existing SB bridge, new signals and major utility relocation. The presentation will demonstrate how the 371′ long, 1.5M pound truss was moved and lessons learned along the way.

Tower Erection Engineering for the San Francisco-Oakland Bay Bridge Self-anchored Suspension Span

William Wu • *Klohn Crippen Berger LTD*
David Dowdell • *Klohn Crippen Berger, LTD*

The self-anchored suspension span of the new San Francisco/Oakland Bay Bridge (SFOBB-SAS) is a remarkable and unique structure, utilizing a single steel tower and a single cable to support the 620m long twin steel Orthotropic Box Girder (OBG) deck. The completed structure carries 10 lanes of traffic and a separate bike/pedestrian walkway. It will be the largest self-anchored suspension bridge in the world when completed in the summer of 2013. Erection of the 160m tall tower (T1 Tower) to meet a tight construction schedule and stringent seismic design requirements imposed unique challenges on engineers which called for innovative solutions. This presentation outlines of some of the challenges faced during the staged analysis and design for the construction of the T1 Tower of the SFOBB-SAS.

The 160m high T1 Tower consists of four steel shafts, each made up of four field spliced segments weighing up to 1100 tonnes and having a maximum segment height of 48m. The four shafts are interconnected by shear link beams and cross-braces, and capped by the tower connection grillage and tower cable-saddle. A temporary T1 Erection Tower (T1ET) incorporating a lifting gantry was designed and constructed. The 164m tall T1ET is a braced steel structure built around the T1 Tower and shares the same foundation. The T1ET supports the lifting gantry system and a self-climbing crane which was used to construct the TIET.

The T1ET was constructed in four major stages corresponding to the T1 Tower segment lifts. Work platforms were incorporated at the four T1 shaft field splice elevations. These platforms also provided a diaphragm and bracing system to the permanent T1 Tower which provide T1ET's main lateral support system. Both the T1 Tower and the T1ET were analyzed and designed for dead loads, wind loads, thermal loads, lifting loads and seismic loads at all stages of construction.

Shear link beams connect the four T1 shafts at 20 different elevations. The links are designed to act as yielding fuses in a major seismic event. An average of 3700 bolts are required at each shear link elevation. Tower shaft splices consist of up to 400 plates and 28240 bolts. Making the connections was on the schedule's critical path, so partial bolting patterns were developed for the shear links and Tower splices with the minimum bolts required for stability during construction. The balance for the bolts could then be installed at a later time.

To facilitate the installation of the main cable, the top of the T1 Tower and tower saddle were deflected 550mm using cables anchored to bedrock on Yerba Buena Island to the west. This allowed balancing of the horizontal force components of the free hanging cable before transfer of the deck dead load to the cable. Analysis of a number of options indicated the best method was to pull the T1ET over in stages by disengaging T1ET connections to T1 at various elevations and offsetting T1ET relative to T1 to the east via horizontal jacking at the work platform diaphragms.

Design and Construction of the St. Patrick's Island Pedestrian Bridge

Brent Whitcomb • *Parsons Brinckerhoff*

The St. Patrick's Island footbridge in Calgary, designed by RFR architects and engineers in Parsi, is a three-span, 182 meter (600 ft) long steel network arch structure spanning over the Bow River. With an inherently efficient design scheme, the generous span to depth ratio is optimized parametrically with respect to member geometry and sizes. The slender arches and slim concrete deck have minimal contact with the river banks thereby responding to the openness and the natural qualities of the site.

During the course of the construction several challenges were encountered, the most significant being the unprecedented flooding of June 2013 which washed out critical deck falsework, and causing extensive damage to the bridge deck and steelwork extending the schedule by a full year. Finally, the design itself presented certain construction challenges such as strict fabrication tolerances, the sequencing of installation operations, and hanger cable tensioning so that the arches and deck work together as a network arch.

Presented within is an overview of the design criteria and methods, fabrication and construction, flood recovery efforts, and finally the opening of this landmark bridge affectionately known in Calgary as the "skipping stone bridge."

4D BRIDGE REHABILITATION AND REPLACEMENT

San Elijo Lagoon Bridge Replacement

Jeremy LaHaye • *T.Y. Lin International*
Kumar Ghosh • *T.Y. Lin International*
Dan Fitzwilliam • *T.Y. Lin International*

The California Department of Transportation (Caltrans) proposes to improve the Interstate 5 (I-5) over the San Elijo Lagoon as part of Segment 1 of the I-5 North Coast Corridor (NCC) Project. The I-5 NCC Project's main purpose is to maintain or improve the existing and future traffic operations on I-5 in order to improve the safe and efficient regional movement of people and goods for the planning design year 2050. Funding for the project is expected to come from a variety of sources including state, federal, and other fund types. Due to close proximity of the project to the coastline and improvements within environmentally sensitive areas, several stakeholders including Caltrans, the San Diego Association of Governments, the California Coastal Commission and various local and resources agencies are involved in the project development.

The project at San Elijo Lagoon includes replacement of the existing Lagoon Bridge with a 560 ft long and approximately 300 ft wide structure to accommodate the widening of the freeway and increasing the lagoon channel opening. The new bridge will be 220 ft longer and 160 ft wider than the existing bridge. A pedestrian bridge is also required to provide connectivity between the multi-purpose trails on either side of the lagoon. The San Elijo Lagoon Bridge is designed as a unique structure that compliments lagoon viewshed in accordance with the I-5 Design Guidelines. The three-span haunched box girder freeway superstructure maximizes span lengths and accentuates the open views from the trails. The haunched structure also minimizes the structure depth over the trails and the local roads to provide the required vertical clearances. A CIP/PS slab pedestrian bridge suspended from the freeway bridge through steel suspenders minimizes impacts to the lagoon and also enhances the user experience of the multi-purpose trail.

Due to construction staging requirements the freeway bridge was designed as 4 separate segments. The proximity of on-ramps and off-ramps connecting to local roads makes the two outer bridge segments width vary resulting in design challenges. A 3-dimensional grillage model was used to capture the effects of variable width, variable depth and number of girders. Since the structural behavior of the pedestrian bridge is linked to the highway bridge a combined model was required for the two structures. A staged construction analysis was also necessary to model the stressing sequence of the individual cable suspenders. The pedestrian bridge is considered to be a "non-standard" bridge per Caltrans bridge design guidelines. A bridge specific design criteria was developed for the pedestrian bridge in cooperation with Caltrans Department of Engineering Services to account for pedestrian induced vibrations and seismic loads.

Caltrans is utilizing the Construction Manager/General Contractor (CMGC) delivery method for the NCC project. This allows for dialogue between the owner, designers, biologists and the contractor during the design phase itself to identify risks, foster innovation, provide costs projections and refine the project schedule. This is particularly beneficial for this project where constructing the two bridges over an environmentally sensitive lagoon present unique construction challenges. The NCC project is currently scheduled to begin construction in 2015.

Tioga Pedestrian Bridge: Replacing What Once Was

Bob Grubbs • *Oregon DOT*

Along the wild and scenic North Umpqua River, there once stood a timber truss bridge atop massive concrete piers. In 1967, a flood of historic proportions washed the timber superstructure away, leaving only the concrete piers standing.

Over 40 years later, the Bureau of Land Management and Oregon DOT teamed together to once again span the North Umpqua River. It took innovative contracting, reutilization of existing structural members, and teamwork to accomplish the task. The results, a landmark structure that the community and users adore.

Alexander Avenue Bridge Retrofit Project Larkspur, California

Carlos Ramirez • *Parsons Brinckerhoff*

Built in 1925, Alexander Avenue Overhead is a historically significant structure in the City of Larkspur California. It was originally designed to span the railroad right-of-way that ran underneath, with steep approaches to provide adequate clearance over the tracks. When railroad operations ceased, the rail right-of-way below the structure was converted to a pedestrian and bicycle path. The structure serves a vital function serving motorists, bicycles, and pedestrians. In 1984, the Alexander Avenue Overhead was listed on the National Registry of Historic Places. The structure is approximately 163 feet long and 29 feet wide, with seven spans. The longest is a reinforced concrete thru-arch, spanning over the pedestrian and bicycle path. The remaining spans are reinforced concrete slabs. The substructure consists of multi-column concrete bents. In coordination with the City of Larkspur and Caltrans, federal funds were made available for the retrofit and rehabilitation of this bridge.

As-built plans were not available; therefore, a non-destructive investigation and inspection was performed to document the bridge condition and to locate concrete reinforcing within the structural elements. The information gathered was used to perform seismic analysis and finite element analysis of the deck structure under truck loading scenarios.

The controlling fault at the structure location is the San Andreas Fault, with a maximum credible earthquake (MCE) of 8.0. The primary philosophy for the seismic retrofit strategy was to prevent collapse of the structure and to reduce irreparable structural damage. The retrofit components included adding reinforced concrete section to the existing concrete columns at Bents 3, 4, 5, 6 and 7 to increase the column ductility and shear capacity; adding an infill shear wall at Bent 2 to prevent shear failure of the existing concrete columns; strengthening the existing cap beam elements at Bents 3, 4, 5, 6 and 7 by adding reinforced concrete section to prevent hinging or shear failure of these elements; and adding approach structures at the abutments to maximize the mobilization of the passive earth pressures provided by the soil behind the abutments and to limit structure displacements.

The structure had a sufficiency rating of 29.8 and was listed as "Structurally Deficient". Major repair efforts were required for the concrete deck, to prevent water penetration and further deterioration, as well as to ensure that the concrete deck is able to transfer lateral seismic load between the bents, tie beams, and cross beams. The existing asphalt concrete overlay and unsound portions of the bridge deck were removed. The bridge deck was then treated with a high molecular weight methacrylate resin system and overlayed with polyester concrete. The goal of the rehabilitation design was to extend the useful life of the structure, allowing emergency vehicles and local traffic to continue to use the structure. All restoration and repair work was conducted in accordance with the National Park Service, U.S. Department of Interior, Preservation Brief 15: Preservation of Historic Concrete.

5A ACCELERATED BRIDGE CONSTRUCTION

Faster Construction and Better Seismic Performance; You *Can* Have Both

John Stanton • *University of Washington*
Marc Eberhard • *University of Washington*

A new bridge bent system has been developed to provide 1) reduced on-site construction time, 2) minimal residual displacements after even a large earthquake and 3) reduced seismic damage. The new system's performance characteristics improve over those of a conventionally constructed bridge by: using precast concrete components with site connections that are simple and fast to make and offer generous tolerances; pre-tensioning the column with strands that are bonded only at the ends and are debonded over the clear height of the column; and designing special confinement details to protect the plastic hinge region.

The system has undergone several stages of development, starting with connections for a non-prestressed, precast system. Those were tested in the laboratory and that system was then implemented in the field in a bridge over I-5 in the State of Washington, which demonstrated its ease of construction. That system was then developed further by introducing a combination of conventional bar reinforcement and partially debonded pre-tensioned strands to provide the flexural strength. The columns rock as rigid bodies on the foundations and cap beams, the strands remain elastic under the design earthquake and bring the columns back upright, while the bonded bars yield cyclically and dissipate energy. The critical connections between the column and the footing and cap beam were tested under quasi-static loading and were found to provide good re-centering properties. Several different designs were tested for protecting the ends of the rocking columns against damage, and use of a short steel confining tube at each end was found to be the most effective.

The paper describes the design philosophy of the new bent system and reports on shaking tests conducted on a 25% scale model of the pre-tensioned version of the bridge. That test specimen had two spans and three bents, and was subjected to a series of increasingly severe ground motions. It behaved as intended up to the design earthquake, sustaining only cosmetic damage and exhibiting excellent re-centering properties. The intensity of the motions was increased until the tables' limits were reached using the Century City (1994) motion, after which the 1995 Takatori motion, which contains a large pulse component, was used in an attempt to cause damage. At the end of all testing, the columns were within 0.2% of vertical and the bridge had sustained fractured reinforcing bars but essentially no concrete damage.

Innovative, Accelerated, and Cost Effective Options for Short Span Steel Bridges

Michael Barker • *University of Wyoming*

States and counties are replacing significant numbers of simple-span bridges in their inventories. Standardized short span steel bridge designs and practical details significantly reduces design time and fabrication costs, provides cost effective solutions, and increases construction efficiencies. eSPAN140 is a free online design tool (supported by the Short Span Steel Bridge Alliance) that creates real-time standardized simple-span steel bridge designs, details and plans. The interactive web-based eSPAN140 design package allows bridge designers and owners to quickly consider alternative steel solutions to meet bridge project needs, including supporting information on constructing steel bridges, coating systems, technical design resources, project case studies, and manufacturer solutions. In addition, new standardized Press-Brake Tub Girder systems are available for modular designs and accelerated bridge construction needs.

Novel Deconstructible and Resilient Columns for ABC in High Seismic Zones.

Sebastian Varela • *University of Nevada, Reno*

As part of an ongoing research project funded by the National Science Foundation, experimental and analytical studies were conducted on novel deconstructible bridge columns that can undergo intense earthquake loading and yet remain functional. Smart materials such as superelastic shape memory alloy (SMA) bars, engineered cementitious composite (ECC) or elastomeric base elements, and fiber-reinforced polymer tubes with carbon and glass fibers were combined in order to effectively provide the desired seismic performance to the columns consisting of low residual drifts with minimal damage and degradation of capacity. The project is collaborative with four small business partners from California and northern Nevada that are active in the development and application of the novel materials that were used. A unique concept in which the columns are designed to be detachable was also developed. This concept does not only provide the inherent advantages of accelerated bridge construction (ABC), but is also expected to facilitate material recycling and component reuse when the structure is obsolete, thereby reducing energy consumption and carbon footprint from material extraction and manufacturing.

During the experimental studies, a total of six quarter-scale single column models and two 2-span bridge models approximately 70 ft. long each were tested using shake tables under simulated near-fault motions from the 1-17-1994 Northridge, California earthquake. Both the individual columns and 2-span bridge models displayed low residual drifts and loss of capacity even after being subjected to drift demands in exceedance of 6%, and 8%, respectively. Damage to the columns was found to be minimal and limited to the detachable plastic hinge elements. It was concluded that a bridge using these novel column elements could remain functional after an intense earthquake, while a comparable conventional reinforced concrete counterpart would be rendered inoperative. This presentation should be of interest to a broad audience from practicing to consulting engineers to researchers. The presentation will outline the main findings and observations of the test program, as well as a description of the novel concepts that were explored and challenges encountered during the design, construction and testing phases. The presentation will be targeted to researchers and practitioners in the field of earthquake engineering of bridge systems, who could benefit from the analytical and experimental techniques that were adopted and the practical design implications of the results.

5B BRIDGE RESEARCH AND ANALYSIS

Instrumenting Anchorage Zone of Post-tensioned Box Girder Bridges

Ahmed Maree • *University of Nevada, Reno*
Marc Friedheim • *California Department of Transportation*

Adequate anchorage zone performance is critical to the proper performance of post-tensioned bridges. Post-tensioning anchorage zones of box girder bridges need to have adequate reinforcement and proper concrete placement. It is essential that sufficient reinforcement be provided to handle the spreading of forces in the general zone of the end anchorage. It is also critical that concrete stresses remain sufficient low to prevent crushing especially in areas immediately ahead of the anchorage device and at changes in geometry. Current design codes do not provide a clear method for design of anchorage zones at end diaphragm. Available design equations can be used only for rectangular sections. In case of box girder, the cross section changes from wide rectangular section through the diaphragm to an I-Shape section at the webs of the box girder. Current design methods have led to congested anchorage zones. There have been construction issues and cracking problems in anchorage zones. .

In order to study the performance of anchorage zones, end diaphragm of box girders were instrumented in the field. Different types of strain gauges were used in order to capture strains on reinforcing bars, and within the concrete elements. The field investigation enables the measurement of the flow of strains in the structure. Through these strains, the flow of forces was determined. A finite element model was developed. This model gives good correlation with experimental results obtained from previous literature. Using the developed finite element model, 3-dimensional spreading that occurs in the anchorage zones of box girder was determined. Also the key variables affecting anchorage zone of box girder were identified. Developing realistic models are needed to understand the behavior of anchorage zone, determine the actual safety margin during construction, estimate minimum requirements for elements' dimensions and calibrate the adequacy of existing amounts of reinforcement.

Structural Response of Bent Caps in Reinforced Concrete Box-Girder Bridges

Mohamed Moustafa • *University of California, Berkeley*

Bridges are key components of infrastructure that are vulnerable to earthquakes and many are undergoing retrofit or complete replacement. Optimized seismic design of new bridges and informed retrofit decisions are indispensable. A specific design issue that is concerned with the structural response of bent cap beams in as-built and retrofitted box-girder bridges under gravity and seismic loads is tackled in this paper. A combined experimental and computational research was undertaken in this study to investigate the bent cap capacity and effective slab width in reinforced concrete box-girder bridges for enhanced seismic capacity design approach. Two large-scale as-built and retrofitted column-bent cap-box-girder subassemblies were developed and tested using bidirectional quasi-static cyclic loading and hybrid simulation approach, respectively. In addition, detailed finite element models were calibrated and further used to complement the experimental programs. The study revisited the effective slab width code values for bent caps and concluded that the slab reinforcement within an effective width, especially in tension, should be included for accurate bent cap capacity estimation. Accordingly, recommendations are suggested for the relevant bridge seismic design codes.

Computer-Aided Design, Analysis, and Load Rating of Precast-Prestressed Spliced Girder Bridges

Rick Brice • *Washington State Department of Transportation*

Without automated computations, the design, analysis and load rating of precast-prestressed spliced girder bridges is a complex and time consuming endeavor. This paper will discuss general concepts of computer-aided analysis for spliced girder bridges and will present a case study of a new computer-aided design tool from the Washington State Department of Transportation. Spliced girder designs must account for the effects of construction stages, changes to the statical structural system, pre-tensioning, post-tensioning, hyperstatic actions, non-homogeneous non-prismatic composite cross sections, and time dependent material responses including creep and shrinkage of concrete, and relaxation of prestressing steel. Millions of calculations must be carried out for a rigorous analysis. Additionally, engineers must ensure designs meet or exceed the numerous requirements of the AASHTO LRFD Bridge Design Specifications. Load ratings must conform to the requirements of the AASHTO Manual for Bridge Evaluation for design, legal, and permit loading conditions. Computer-aided design is the most feasible solution for precast-prestressed spliced girder bridges.

5C FOUNDATION DESIGN AND CONSTRUCTION

Thermal Integrity Profiling as a Drilled Shaft Quality Assurance Tool

Mark Gaines • *Washington State Dept. of Transportation*

The Washington State Department of Transportation (WSDOT) has been constructing deep drilled shafts since 1950s. Drilled shafts in Washington State are typically between four and 12 feet in diameter and have been extended to depths in excess of 260 feet. Most shafts are installed below the water table, making inspection and quality verification challenging. For the last 20+ years, WSDOT has accepted drilled shafts based on cross-hole sonic log testing. While this method has served us well, it has certain limitations. Specifically, it provides no way to verify the amount and quality of the concrete cover outside of the shaft reinforcing cage and it is often difficult to determine the quality of the concrete at the tip of the shaft.

WSDOT recently completed a pilot project using a new method of drilled shaft non-destructive testing called thermal integrity profiling (TIP). This test method provides all of the benefits of cross-hole sonic log testing while addressing the shortcomings described earlier. Thermal integrity testing works by embedding arrays of thermocouples around the perimeter of the shaft. Thermocouple arrays are tied to the reinforcing cage before it is placed in the shaft excavation, and are extend from the bottom of the shaft to the top. Data collection from the thermocouples begins as soon as the concrete is placed, and is maintained for seven or more days. As the drilled shaft concrete hydrates, the thermocouples detect the heat generated during the hydration process. Thermocouple data is recorded at specific intervals through a data collection system. When the owner wants to verify the integrity of the shaft, the temperature data is downloaded and post-processed to develop a thermal plot of the shaft. A number of factors affect the heat signature of the shaft, including soil type, elevation of the groundwater table, geometry of the shaft, and cementitious content of the concrete. The post-processing takes these factors into account in developing the thermal plot. Anomalies are identified when the recorded temperatures are low due to factors like soil contamination of the concrete or reduced concrete cover.

This presentation will discuss the basic elements of the thermal integrity testing system and describe some of the challenges identified during the installation and testing process. The results of the pilot project will be shared and a comparison will be provided between the cross-hole sonic log results and the thermal integrity testing results. Finally, some thoughts will be provided on the future of thermal integrity testing for drilled shaft acceptance in Washington State.

Honolulu Rail Transit Project: Drilled-Shaft Design Considerations and Challenges

Ahilan Selladurai • *AECOM Transportation*
Ahmad Abdel-Karin • *AECOM Transportation*

The Honolulu Rail Transit Project (HRTP) is one of the major development projects in Hawaii and the United States overall. AECOM was awarded a two-segment design contract from the Honolulu Rail Transit Authority. AECOM was responsible for designing a 386-span elevated guideway superstructure and substructure.

Special design criteria were developed and implemented because of the project's proximity to high seismic zones. The substructures consist of several types of bents: typical single-column, straddle, cantilevered straddle, C-type, station hammerhead, and station straddle bents. The project included 435 drilled shaft foundations supporting the various configurations. For each pier, the geotechnical engineer performed individual borings and provided recommendations for seismic site class and all other soil information. The design of the drilled shafts for all piers, each with its own geotechnical data, required extensive engineering effort. The project design criteria required that the shaft design be based on two categories for the seismic demand load: Shafts located in higher seismic demand zones (based on soil characteristics) were designed more conservatively as "capacity protected" elements by applying the columns over-strength shear and moment demands to the top of the shafts. All other shafts were designed based on the response spectra analysis (RSA) forces.

The geotechnical engineer provided suggestions to reduce shaft diameter by 1 foot at 18 feet below the top of the shaft (stepped shaft), where possible, to reduce the required lateral stability length.

The "stepped" shafts had to meet additional design and detailing requirements. Every drilled shaft was designed for strength-, extreme- (including seismic), and service-limit state loads. Macro/VBA programmed Excel spreadsheets were created to complete several complicated repeating calculations in an effort to handle the large amount of data processing.

The presentation will include more detailed information about project design criteria, key features/provisions, various geotechnical recommendations, and site restrictions. Furthermore, this presentation will include the engineer's recommendations regarding "best practices" for processing, manipulating, and analyzing a large amount of data, along with design procedures for designing a large number of drilled shafts for strength, service, and extreme-limit state loads.

Sellwood Bridge Perched Box Caisson Design & Construction

Garret Ellingson • *McGee Engineering*
Shayne Tennis • *McGee Engineering*

How do you construct an in-water bridge pier when a conventional cofferdam is not constructible? The solution: build a perched box caisson. At the $307.5 million Sellwood Replacement Bridge project in Portland, Oregon, two submerged tubs were designed and constructed to function as cofferdam alternatives while forming and pouring the concrete piers. This solution offered several additional benefits including reuse of pile used during drilled shaft installation, accelerated construction schedule for work associated with in-water permits, and more. These temporary works structures have been successfully in use for over a year and have already served their primary function. This presentation will discuss the constraints of the project, the design process, construction methods, and the pros and cons of this type of structure.

5D BRIDGE MATERIALS AND MAINTENANCE

Specialized Post-Tensioning Inspection and Repair

Travis Green • *Wiss, Janney, Elstner Associates, Inc.*
Eric Anderson • *Wiss,Janney, Elstner Associates, Inc.*

Post-tensioned structures have been in use in the United States for over 40 years and their performance to-date has, in general, been good. However, in recent years, concerns related to post-tensioning tendon corrosion have been raised in a small number of bridges, most notably in Florida and Virginia, where investigations have linked post-tensioning strand corrosion to grout voids and poor detailing. While these structures are subjected to periodic routine inspection, they are not subjected to periodic hands-on inspections like fracture critical bridges. Recently, several agencies have elected to conduct trial specialized post-tensioning investigations. Many of these investigations focus on identifying and addressing problematic conditions like unprotected anchors and tendon grout voids, while others have focused on confirming the presence of elevated chloride levels in the grout.

Assessment of post-tensioned structures is particularly challenging since tendons are often not readily accessible. Further, repair of internal, external, and stay cable systems requires close coordination between the owner, engineer, and a specialty support contractor familiar with post-tensioning systems. WJE and VSL have performed specialized post-tensioning inspections and repairs on over 25 bridges across the United States. This work can include a combination of activities such as: reviewing inspection records; prioritizing each structure and the tendons within the structure; inspecting representative tendons; performing grout testing; performing corrosion testing; and designing and installing repairs. The exact approach largely depends on the Owner's budget, depth of past inspections, and the extent of issues found during inspection. Repairs can include remedial grouting, external tendon replacement, anchorage protection, HDPE pipe repairs, and strengthening.

Along with these specialized inspections, WJE has been researching new technologies as well as adapting old ones to help improve the efficiency and accuracy of these inspections. Some of these technologies include MIRA tomography scanning which utilizes powerful shear waves to interrogate concrete elements as well as infra-red thermal scanning to identify potential voids in post tensioning conduit.

Following the completion of specialized inspections, corrosion monitoring systems have also been employed. These efforts include utilizing commercially available monitoring systems installed within grout voids to facilitate long-term monitoring of the prestressing steel strands and the associated galvanized metal ducts. With these systems, data can be collected relating to numerous factors including the corrosion rate of the steel as well as temperature and resistivity of the encapsulating grout.

In our experience, specialized post-tensioning inspection and repair are not routine tasks for most agencies. Therefore, this presentation illustrates typical inspection activities and observations as well as common repair techniques using case studies.

Bridge Security, Architecture & Urban Design: Crime Prevention Through Environmental Design

Paul Kinderman • *WSDOT Bridge Architect*

Security based bridge design and its direct correlation to modern social issues is addressed in this presentation. Criminal activity, illegal encampments, graffiti, hindrance to economic development and public eyesore create unwanted expensive. They also pose safety hazard for State Maintenance and Operations practices. The issue exists in urban areas as well as rural and recreational locales.

WSDOT policy and design is determined on a case by case basis using two strategies. These strategies are universally accepted best practices. The first, Crime Prevention through Environmental

Design (CEPTD), is a multi-disciplinary approach to deterring criminal behavior. The second, Context Sensitive Design (CSS), is also multi-disciplinary and focuses on project development methods. Multi-disciplinary teams consist of engineers and architects but may include law enforcement, local businesses, social service providers, and psychologists.

CPTED principals are based upon the theory that the proper design and effective use of the built environment can reduce crime, reduce the fear of crime, and improve the quality of life. Built environment implementations of CPTED seek to dissuade offenders from committing crimes by manipulating the built environment in which those crimes proceed from or occur. The six main concepts are territoriality, surveillance, access control, image/maintenance, activity support and target hardening. Applying all of these strategies is key when preventing crime in any neighborhood or right-of-way.

Development of National Training for Bridge Maintenance

Eric Thorkildsen • *Greenman-Pedersen, Inc.*

The Federal Highway Administration through its instructional arm the National Highway Institute is developing comprehensive training for bridge maintenance workers comprising of web based training, instructor led training and development of a reference manual. Greenman, Pedersen, Inc was selected to develop the instruction. The reference manual is complete and is over 1,000 pages long and contains over 50 written procedures, 20 job order checklist and decisions aid matrices covering typical bridge maintenance preservation activities and repairs. This session will cover key elements of the training and the challenge of developing for a national audience.

6A BRIDGE DESIGN AND CONSTRUCTION

Design and Construction Complexities of the Yerba Buena Island Transition Structures for the New East Span - SFOBB

Robert Dameron • *Moffatt & Nichol*

This paper focuses on the engineering during construction for the Yerba Buena Island Transition Structures (YBITS) portion of the New East Span – San Francisco Oakland Bay Bridge (SFOBB) Seismic Safety Project. The YBITS are a pair of 26-m wide, 460-m long, Cast-in-Place on falsework, post-tensioned box-girder bridges. A key challenge for future seismic, thermal, and live-load performance, was the design and construction of the hinges connecting YBITS to the iconic Self-Anchored Suspension (SAS) span of SFOBB.

The east end of both the Westbound and Eastbound structures terminates in a 61-meter cantilever span which ultimately supports "Hinge K". Hinge K joins the YBITS to the SAS; it accommodates two 1.9-meter diameter pipe-connectors designed to transfer vertical and transverse loads, but to allow longitudinal expansion and rotation across the hinge. The Eastbound structure is further complicated by addition of a 5.8 meter wide bike-path to be implemented many months after bridge opening. Design challenges covered in the paper include prediction and accommodation of varying displacement along the structure (which has bent heights ranging from 10 meters to 49 meters), and the seismic performance of Hinge K which joins very dynamically dissimilar structures. Other challenges described include camber control and time-dependent effects analysis, accounting for creep, shrinkage, and construction staging, such that final elevation of Hinge K matched the SAS with a proper level of vertical force transmitted to the pipes to achieve robust, long-term live-load carrying performance.

Replacement of the Highway 85 Bridge over the Missouri River Near Williston, North Dakota

Michael Marks • *KLJ*
Colin Moran • *KLJ*

As part of an $186,000,000, 40 mile long Highway 85 corridor improvement in northwestern North Dakota, the existing 1500 ft long steel two-girder Lewis and Clark Bridge over the Missouri River is to be replaced by a six span continuous weathering steel multi-plate girder structure. Due to the significant increase in oil extraction activity in the region, the average annual daily traffic on the bridge increased by over 400% between 2009 and 2014 with approximately 40% of this being trucks.

A comprehensive fatigue analysis performed on the existing fracture critical structure revealed that due to its particular steel detailing combined with the traffic increase; the bridge was reaching the end of its fatigue life and was geometrically inadequate. Therefore, rehabilitation was not practical.

A preliminary analysis of various new bridge alternatives was done and included steel I-girders, steel tub girders and concrete segmental. The steel I-girder alternate was chosen due to its more efficient constructability at this particular site, greater ability to meet the project schedule and lower cost. Due to the results of an USACE Aggradation Study of the site, the steel girder alternate also provided the ability to achieve the increased minimum underbridge clearance required by incorporating haunched end spans.

The final bridge configuration is a six span fully continuous weathering steel structure with an overall length of 1522 ft. The cross section consists of two lanes in each direction with an overall width of 84.5 ft. The seven, 8.5 ft. deep girders are spaced at 13 ft and support a cast in place concrete deck. The substructure consists of cast in place abutments and arched hammerhead piers founded on 250 ton steel H-piles. The bridge was designed utilizing the MDX Line Girder analysis software with a 3D influence surface model done to verify the results.

The project was bid in July of 2014. The low bidder was Johnson Brothers Corporation, Fort Worth, Texas with a bridge cost of approximately $34,000,000, 19% below budget. The structure is currently under construction and is due to be completed by the summer of 2016.

This project demonstrated that through the use of weathering steel, a cost effective and constructible bridge was able to meet the tight timeframes and the logistical challenges of this remote site.

US 34 Missouri River: Pushing the Design and Construction Limits for a Haunched Steel Girder with Substringer Bridge

Phil Rossbach • *HDR Engineering, Inc.*

6B BRIDGE DESIGN AND CONSTRUCTION

Maximizing the Flexibility of Precast Concrete to Accommodate Unusual Bridge Geometry in a Constrained Urban Environment

Yuling Teo • *CH2M Hill*
Hong Guan • *CH2M Hill*
Mark Johnson • *CH2M Hill*

As a partnership between the Port of Seattle and the City of Seattle, the East Marginal Way Grade Separation project constructed a new overpass over the BNSF and UPRR railroad tracks in the SODO neighborhood south of downtown Seattle. The new overpass improves road and rail access to Port terminals, intermodal rail yards, and regional manufacturing and distribution facilities by reducing vehicle delay by as much as 270 hours daily compared with the existing at-grade crossings. The overpass also benefits motorists and industrial traffic moving to and from West Seattle through increased mobility and improved safety.

Located between the Spokane Street Viaduct and Highway SR99, the constrained site called for a bridge with highly unusual geometry. The superstructure of the 4-span overpass forms a Y-shape, with two end spans extending to the east and west north of the railroad tracks, and another end span leading southeast of the railroad tracks. All three end spans merge at a trapezoidal-shaped center span over the railroad tracks, resulting in a deck width varying from approximately 75′ at the narrowest point to approximately 150′ at the widest location.

To accommodate this unusual geometry, the superstructure was initially designed using hybrid precast/cast-in-place post-tensioned concrete girders, requiring extensive falsework in close proximity with active railroad tracks. Through a Cost Reduction Incentive Proposal (CRIP), the contractor replaced the original superstructure design with precast, prestressed concrete I-girders to accelerate the bridge construction, mitigate impacts to railroad operations, and reduce the superstructure weight to allow for smaller substructure and foundations. However, the revised design introduced unique technical challenges. Not only did each precast girder have a different length and design to accommodate the unusual deck geometry, but the girders for the center span were designed with built-in induced pre-camber. The 13″ pre-camber resulted in a girder profile that curves upwards to provide the necessary vertical clearance over the railroad tracks. This pre-camber is among the largest fabricated for precast prestressed I-girders in Washington State.

In addition, the substructure design was affected by the site constraints and unusual bridge geometry. The location and shape of the pier bent caps were limited by clearance requirements for the railroad, resulting in an irregular T-shaped bent cap at one of the piers. This complicated the seismic design and detailing by introducing significant torsional moment in the bent cap.

This presentation will focus on the unique design and construction challenges for the East Marginal Way Grade Separation project, including:

- Prediction and control of camber for girders with induced pre-camber.
- Establishing precise live load and dead load distribution for the precast beam-slab structure with complex geometry.
- Seismic design challenges resulting from the unique substructure geometry.
- Detailing issues and lessons learned from construction in close proximity to active railroads.

Salt Creek Half Viaducts

Bob Goodrich • *OBEC Consulting Engineers*

The original project was designed to replace four half-viaducts and rehabilitate a tunnel. During the initial phase, OBEC was retained by the contractor to design precast bridge elements to speed up construction and reduce the quantity of concrete to be transported to the remote site. Bridge components include modular concrete walls and precast, post-tensioned deck. This included half-viaducts located in horizontal curves.

Part way through construction, due to issues with progress and schedule, ODOT elected to terminate the construction contract with two of the replacements still incomplete. At this time, ODOT retained OBEC to prepare a bid package to complete the partially constructed project. The bid used best-value contractor selection which includes both project approach and cost. The remaining work included preservation and rehabilitation of a historic building beneath one of the half-viaducts that serves as the tunnel control room. Construction staging considered a high truck volume, a short construction window due to spring and fall inclement winter weather, an extremely constrained site, and substantial completion in one season.

The presentation will focus on the precast bridge elements, complex staging and results of construction.

MSS Box Girder Transverse Design of Gerald Desmond Bridge Replace Project

Sammy Tu • *STV INC*

This presentation presents transverse design and analysis for approach spans of Gerald Desmond Bridge Replace Design Build Project which is currently under construction.

This $1.2 billion project consists of 2,000 foot long, 6 lane signature cable-stayed bridge (1,000-foot main span), with over 6,000 feet of approach viaducts (up to 200 feet high). The West and east approach structures consistent of single and multiple cell box girders using Movable Scaffolding System construction.

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

1. Transverse analysis considerations for MSS construction
2. Analysis strategy and methodologies
3. Comparison of reinforced transverse design and post-tension design
4. Longitudinal and transverse combined effects
5. Recommendations of design and analysis for large size box girders in long span bridges

6C BRIDGE MATERIALS AND DETAILS

Material Properties of Lightweight Concrete for Bridge Design

Reid Castrodale • *Expanded Shale Clay and Slate Institute*

While structural lightweight concrete has been used in bridges in the US since the 1930s, many designers are reluctant to use the material. One reason is an uncertainly of the material properties of lightweight concrete to be used for the design of bridges. Recent field experience and testing have demonstrated that the mechanical properties of lightweight concrete are well-suited for design of bridges.

This presentation will discuss the material properties of structural lightweight concrete that are of importance in the design and performance of bridges. The properties discussed will include modulus of elasticity, splitting tensile strength, compressive strength, creep and shrinkage. The impact of these material properties on design of bridge elements will also be presented, including recent changes to the AASHTO LRFD related to lightweight concrete.

Good Bridges, Bad Details, and Ugly Cracks: A Study in Titanium Alternatives to Fiber Reinforced Polymers

Paul Strauser • *ODOT*

The Mosier Connection over Hwy 002 case study contains start to finish coverage of ODOT's response to longitudinal tension failures in reinforced concrete deck girders (RCDG). Oregon's bridge inventory is widely populated with these vintage structures, commonly containing insufficient flexural reinforcement anchorage. Although prevalent, these details seldom result in damage to structures. Come listen to the story of how these issues arise and discover a new range of cost effective, titanium strengthening alternatives being developed and used by Oregon State University and the Oregon DOT.

Crack-Less Bridge Decks

Craig Knapp • *Caltrans*

Bridge owners have widely accepted that the durability of concrete bridge decks is compromised by the presence of cracks and that a major source of cracking is concrete shrinkage. Research on concrete shrinkage started well over a century ago and these efforts have resulted in an understanding of the factors that impact concrete shrinkage. This knowledge paired with newly available tools have resulted in a reliable, pratical and cost effective method for constructing bridge decks with minimal or no cracking due to shrinkage stresses.

6D INVENTORY AND MAINTENANCE

Utilizing 3-D Models for Better Bridge Asset Inspection and Management of Complex Bridges

Lee Tanase • *Bentley Systems*

Complex bridges are owned and maintained by numerous agencies across North America and the World. Keeping these structures operating safely and efficiently requires a detailed inspection and maintenance process with extensive amounts of data to be collected and analyzed. An individual report of the findings on a single bridge can easily exceed 1,000 to 2,000 pages in length for each inspection. To assist in the inspection and management process a new 3-D Visualization software solution has been used to collect inspection data and display the results and management tasks via an enhanced visualization and scheduling system. Inspectors are also customizing the software as they add or change features according to their preferences. Detailed paper reports can be generated along with exporting subset data in formats which comply with requirements from Federal Highway Administration and specific DOTs.

The three-dimensional visualization software offers the ability to "fly through" the bridge to view elements at multiple angles and viewpoints while also drilling down to find out more about trends, deterioration patterns, and other preservation related data. Users can click on individual members to see properties, pictures, ratings, and history while also visualizing results on the model (i.e. show all Gusset Plates in fair or poor condition – the Gusset Pltes matching would be shown in red and all other elements in black). Every steel vertical/diagonal, gusset plate, bearing, etc. can be individually identified with comments, history, and pictures attached. The objective of the software is to re-create the bridge as if an inspector is actually at the job site while maintaining a repository of all element and structural data for review and analysis. This has become a best practice for numerous agencies and those practices will be shared for the audience.

Where's the Guidance? An Interim Approach for Load Rating Culverts and Flexible Buried Bridges

Joel Hahm • *Big R Bridge*

Much effort has been focused on load rating of bridges for vehicular loads, while until recently load rating for the nation's culvert and flexible buried bridge inventory has had relatively little rating attention. This easily involves hundreds of thousands of structures nationwide. Most bridge load rating is focused on the gross truck weight and known loads and structure properties, while the response of typical culverts and flexible buried bridges is usually driven by the response to a single axle and often a single wheel and can depend on unknown factors. The AASHTO LRFD Manual for Bridge Evaluation (MBE) provides a lot of useful tools and procedures for load rating existing bridges for current design requirements. However, the MBE does not address load rating for culverts or flexible buried bridges and many states don't have the budget to dedicate people to evaluating and rating buried structures. There is an NCHRP study getting ready to start to address rating these types of structures but the question remains: "What do I do until then?"

There have been resources and/or tools developed by some consultants, states, and industry organizations to perform load ratings for these types of structures, but approaches vary and in general have attempted to apply calculations and principles that were developed for traditional bridges – much of which is not applicable for buried structures. Calculations are often complicated and difficult to follow and result in rating factors that don't pass the smell test. Most of these methods also do not consider soil-structure interaction and structure geometry, which are critical factors in supporting design loads. To date, there has been no consensus regarding which (if any) of these are correct and none of them have been incorporated into the MBE.

With the lack of consensus on which approach to take the best course might be to keep it simple. The goal of this presentation is to suggest a simplified common sense interim approach for load rating culverts and flexible buried bridges. This approach will focus on proper evaluation of the condition of the structure and site conditions, a realistic approach to design loads, options to improve load rating, and guidelines for evaluating results. Among the specific topics to be discussed are design, materials, foundations, load rating, construction, maintenance, and engineering judgment.

Developing Risk Assessment Protocols for Six Iconic Willamette River Bridges

Douglas Lampkin • *David Evans & Associates, Inc.*
Ian Cannon • *Multnomah County*

Aligned with increased focus on bridge preservation and asset management, this session reveals the inner workings of a unique method of determining a 20-year Capital Improvement Plan for Multnomah County's six major iconic Willamette River bridge crossings in downtown Portland, Oregon. This session will describe the technical approach used to assess current and future bridge needs using an innovative, risk-based approach that considers the consequence of inaction for every bridge component. The process translated current condition, operational, seismic, and user needs assessments into remedies, resulting in a prioritized, 20-year delivery plan for funding and implementation.

The technical components assessed included:

- Bridge Mechanical and Electrical Systems and Components
- Bridge Structural Elements
- Bridge Deck, Sidewalk, and Rail Components
- Ancillary Bridge Components (Expansion Joints, Bearings, etc.)
- Seismic Resiliency and/or Bridge Replacement
- Multi-modal Elements (Bicycle, Pedestrian and Transit)
- Roadway Elements

The speakers will share both the owner and project team perspectives that shaped key decisions in developing this CIP, such as:

- Agreement on what "programmatic" assessment means.
- How and when to best engage stakeholders.
- Defining and gaining consensus on selection criteria between vary incongruent elements.
- Using risk-based technical assessment processes.
- Maintaining adaptability of the plan over time.
- Developing unconstrained vs. constrained needs implementation plans.
- Determining how projects with widely varying needs and objectives should be compared and prioritized.
- Incorporating life cycle needs should be forecast over 20 years.
- Ensuring future CIP flexibility is best incorporated into the prioritization process.

7A BRIDGE SEISMIC DESIGN

Seismic Design of Light Rail Transit Bridges with Fault Rupture

James Gingery • *Kleinfelder*
Ebrahim Amirihormozaki • *Kleinfelder*

The Mid-Coast Corridor Transit Project will extend Light Rail Transit (LRT) service from the Old Town Transit Center to the University City community in San Diego, California. The project, which extends 11 miles and includes 9 stations, will serve major activity centers such as the University of California, San Diego and Westfield University Towne Centre.

Preliminary evaluation of existing maps and vintage aerial photography distinguished several alignment locations likely crossed by active faults. Extensive field investigations were performed at key locations including exploratory trenches, geophysical surveys, continuous core borings, cone penetrometer testing and geologic mapping. Surface fault rupture displacement estimates were developed for design using deterministic and probabilistic methods, and several design scenarios were developed to bracket uncertainties in location, distribution and sense of slip.

The Rose Creek LRT Overhead bridge is an example of bridges along this corridor impacted by severe fault rupture. This bridge will carry two parallel LRT tracks north across the creek and over an existing railroad line for 0.33 miles within the existing right-of-way. The active Rose Canyon Fault Zone crosses the bridge alignment, affecting three foundation supports (Abutment 1 and Bents 2 and 3) and two spans. The faulting consists of primary and secondary zones that cross the bridge obliquely and dip 70 degrees to the west. The design displacements consist of 4 feet of strike-slip and 0.4 feet of vertical throw on the primary fault, and 1.2 feet of strike-slip on the secondary faults. A combination of shallow and deep foundations have been designed to maintain support of the bridge even if they are directly intersected by the fault rupture. The first three spans are designed as simply supported to articulate the fault rupture displacements. The first abutment will also accommodate the horizontal offset in the first span while the span is connected to Bent 2. The rest of the bridge may be subject to slight ground deformations of up to 3 inches due to their proximity to the primary fault. The bridge columns are designed to accommodate this displacement without any significant structural enhancements.

Seismic Design Considerations for Single-Column Piers Supporting Highly Curved Ramp Bridges

Greg Griffin • *AECOM*

Seismic design of curved ramp bridges supported with single-column piers typically are considered as a cantilevered column in the transverse direction regardless of roadway curvature. This design philosophy has led to successful designs in many cases; however, in some instances, this may lead to unconservative designs for others. Due to the superstructure torsional rigidity and highly curved roadway alignments, column end conditions may be closer to fixed at the soffit of the superstructure. A combination of these effects may lead to designs in which plastic hinging may occur unexpectedly at the top of the column in the transverse direction.

An analytical study was conducted to confirm whether hinging at the top of the column might be possible in highly curved ramps. A three-span, cast-in-place box girder bridge using varying roadway curvatures and supported with different foundation types was considered. To predict the structural response, the most-significant modal shapes were identified and combined to define the deflected shape and conduct a global three-dimensional bridge pushover analysis. Results of the study indicated that top of column hinging are likely for certain roadway curvatures and foundation types in higher earthquake zones. Other design considerations such as implications for column shear design and bent cap design for plastic hinging forces in the transverse direction will be presented.

Sellwood West Approach Interchange Bridge: Design Challenges and Project Delivery

Vu Phan • *CH2M HILL*

The Sellwood West Approach Interchange Bridge is composed of four connected bridges on the west bank of the Willamette River in Portland, Oregon and ties into the Willamette River (Sellwood) Bridge. The west approach bridges are part of a larger project to replace the deteriorating Sellwood bridge constructed in 1925. The existing Sellwood Bridge has a sufficiency rating of 2 out of 100, is one of the top 10 state-wide crash sites, and was designated to close permanently within 10 years if no action was taken. Design of the new west approach bridges was completed in the first quarter of 2013. Construction of the bridges is currently underway and is expected to be completed by the end of 2015.

Some unique challenges of the project included:

1. The western bank of the Willamette River is susceptible to a seismically induced landslide. Ground improvement measures were taken within the footprint of the new bridges, but even with these measures, design of the new bridges had to take into account up to 15 inches of ground movement during a 1000 year seismic event. Detailed profiles of the anticipated ground movement around each drilled shaft were used to size the drilled shafts.
2. In addition to the significant landslide movement expected on the bridges, seismic analysis under Seismic Design Category D and live load analysis for a future streetcar was also performed.
3. The structure consists of two approach bridges that merge into the mainline bridge, resulting in a geometrically complex structure. Multiple models were developed using LARSA 4D to analyze the bridges independently and as a combined unit.

The complex geometry of the bridge, which included varying deck widths, tapers, and horizontal and vertical curves were all taken into account to produce an accurate set of models for live load and seismic analysis.

This presentation highlights the challenges encountered during the design of the west approach bridges and discusses the approaches taken and the solutions reached to produce a quality product for the client, Multnomah County. We will also highlight some of the construction currently underway and show how many of the design decisions were implemented.

7B BRIDGE DESIGNS AND SCOUR CHALLENGES

Design of the 13th Street Bridge at Vandenberg Air Force Base for Hydraulics, Scour and Seismic

Tony Sanchez • *Moffatt & Nichol*

The 13th Street Bridge over the Santa Ynez River will be replaced with a new bridge designed to remain in operation with minimal damage after a large earthquake.

Located at Vandenberg Air Force Base in Santa Barbara County, California, the bridge is "Mission Critical," and must remain serviceable even after extreme events such as the 200 year flood and the maximum credible earthquake. A seismic performance criteria for the new bridge was developed based on another critical facility, the new SF-Oakland Bay Bridge, and the designers developed a special design solution to address these issues.

The Santa Ynez River in this area is somewhat unpredictable and is capably of over 120,000 cfs of flow. Additionally, the upper 70 ft of soil is soft material susceptible to scour and liquefaction.

The existing bridge, constructed on small piles, experienced major scour and undermining of the piers after floods in 1970, 1978, 1981, and 2003. Several attempts were made to correct the scour problems. However, the scour counter measures were not effective. In 2013, the government decided to proceed with a project to replace this scour critical and seismically vulnerable bridge.

While bridge cost optimization often calls for short span lengths with smaller foundations, at this site, large and deep foundations best address the hydraulics, scour, seismic and liquefaction issues. So a design with long span lengths was the most economical. This approach, in conjunction with good seismic design principals and detailing practices, was used to provide the enhanced seismic performance needed at minimal cost. The challenges of a deep liquefaction site and large loads from lateral spreading, combined with the enhanced performance criteria required an innovative approach. The key was to engage all of the piles at the piers and abutments to share the seismic loads evenly. This was accomplished using strong abutment shear keys and backwalls, rather than using the traditional method of designing these as sacrificial elements. This approach worked extremely well and was very economical to implement.

The presentation will provide a general overview of the project and describe the seismic design of the bridge including the development of the seismic performance criteria and how the bridge was designed to economically meet the hydraulic and seismic issues simultaneously.

Acquiring and Implementing TIGER Grant Funding for the I-15 Virgin River Bridge #6 Superstructure Replacement and Substructure Widening

Rafael Davis • *ADOT*

Virgin River Bridge #6 is located on Interstate-15 (I-15) in Mohave County of the ADOT Flagstaff District at MP 15.58 and is classified as structurally deficient according to the National Bridge Inspection Standards. I-15 in the vicinity of the project passes through the northwestern corner of Arizona and serves as a vital link between the states of California, Nevada, Utah, and beyond. FHWA awarded ADOT with a 21.6 million in funding from a Federal Transportation Investment Generating Economic Recovery (TIGER) grant. The total cost of the project was 27 million.

The design and construction of VRB#6 was complex and required exhaustive coordination with fabricators, stakeholders, subcontractors, and government agencies. Due to the rugged terrain foundations and substructures varied greatly at each pier and abutment. Geometry of the roadway was complex requiring a super-elevation transition, vertical curve break, horizontal spiral, 45 degree skew, and phased construction. Seismic was relatively high for Arizona. Hydraulic forces were extreme because of the steep terrain which created supercritical flows. The Hydraulic Engineer, Geotechnical Engineer, and Bridge Engineer worked closely to quantitatively determine the bedrock was non-erodible and the new structure would be stable with all erodible material removed under a super-flood condition. Structural analysis was performed for all phases of construction for new girders, existing girders, abutments, piers, and foundations.

I-15 is heavy truck corridor with over 5,000 trucks per day, 20 percent of which are permit freight trucks. The existing bridge required 4 rehabilitation projects in 10 years including emergency repairs for cracking in critical areas of the steel girders. Constant fatigue cracking caused the existing superstructure to be rated "poor" per the National Bridge Inventory system.

If the superstructure for Bridge #6 is not replaced, a weight restriction would have been placed on the bridge beginning in 2016, approaching the end of the bridge's lifespan. It is assumed that the weight restriction will divert permit freight truck traffic (up to 20 percent of truck traffic) to other routes. Since I-15 is a strategic corridor with few alternatives, detour routes are long and circuitous.

The TIGER grant application proved the project enhances the economic competitiveness of the nation through improvements in the mobility of people and goods within and across the region. I-15 is a major transcontinental north–south highway that extends more than 1,470 miles through the states of California, Nevada, Arizona, Utah, Idaho, and Montana. The corridor links the region to Mexico, Canada, and the Midwest through connections with I-40, I-70, I-80, and I-90.

ADOT's TIGER grant application proved the project would create jobs, improve safety, reduce emissions thru fuel savings, use innovative delivery methods, increase travel time savings, and reduce vehicle operating costs resulting in a benefit-cost ratio of 11.3 for dollars spent on the project. The project would provide numerous short term and long term benefits.

The TIGER funding stipulated design, permitting, and construction start quickly. ADOT choice to use the CMAR process which advanced the design schedule, involved contractors in the design process, and reduced risk in construction.

History of the Oldest Bridge Pons Fabricius

Luong (Lou) Tran • *WSDOT*

Pons Fabricius may not be a well-known structure as many other Roman's impressive monuments as Coliseum, Heliopolis, and Pont du Gard... but it is an incredible example of a Roman stone arch bridge that has endured the test of time; it is the oldest bridge that still standing over 2000 years. As we move forward in the 21st century with new design technology and materials that can extend bridge lifespan to 100 years of service and beyond, we may want to step back and learn from the bridges that have been standing for more than 2000 years.

Pons Fabricius still has its' senses of wonders - how was it designed, how was it constructed, and what makes it to last. Pons Fabricius was built in 62 BC, 2077 years ago, by the commissioner of roads Lucius Fabricius, to replace the timber bridge with stone arch bridge, located near the city center of Rome. It was designed with the beautiful-architectural ornamented arch form with the function of carrying pedestrian and transporting goods across the raging flood water. The bridge spans part of the Tiber river with two arches, each around 24.5 meters (~80ft.) in diameter, with the one pier in the middle of the river. The bridge is 62 meters (203 ft.) long and 5.5 meters (18 ft.) wide.

The Roman engineers have carefully come up with ingenious ways of how to design the middle pier to withstand the flood and scour, how to design and select the materials for the arches, how to use the cofferdam techniques to build the foundation, and how to protect the structure to withstand the environment over time.

Pons Fabricius has provided a glimpse of Roman's bridge building in the past – as an engineering marvel structure designed and constructed by the engineers of Ancient Rome - to serve the people throughout the ages.

7C BRIDGE SEISMIC DESIGN

Performance of Bridge Columns Under Long Duration Ground Motions

Mohammed Mohammed • *University of Nevada Reno*

The March 11, 2011 Tohoku Earthquake is a reminder of the possibility of a long duration large magnitude subduction earthquake along the pacific northwest coast of the United States. Current seismic design codes do not consider ground motion duration effects on structures. There have been large differences in conclusions of previous research studies with regard to the effect of ground motion duration on structural performance. This paper presents a comprehensive study that uses experimental methods to investigate the ground motion duration effects on bridge columns. The experimental program includes identical columns that are tested on a shake table using different motions including short duration and long duration motions. The purpose of the project is to propose new design provisions, if necessary, to include duration effects.

Maximizing Bridge Value with Advanced Seismic Analysis

Christopher Pitt • *KPFF Consulting Engineers*

The presentation will compare methods that are conventionally used to seismically analyze bridges with more advanced techniques that have been recently established or are under continuing development. The focus will be on the potential positive impacts using more advanced methods can have on project outcomes, emphasizing conditions in which using these methods can greatly improve overall value for existing and new structures. Specific past and current bridge project examples will be discussed, including new bridge designs, existing bridge evaluations and retrofits.

Specific analysis items discussed will include nonlinear time-history performance-based design of bridges, foundation flexibility, including rocking of spread footings and other soil-structure interactions, a discussion of important modeling decisions and available software tools, and proposed modifications to DOT seismic evaluation and retrofit criteria. On-going research and actual project examples will be referenced throughout.

Key Elements & Learning Objectives:

- Rapidly advancing computing technology, continuous seismic research, and development of more sophisticated software tools have made advanced seismic analysis a feasible option.
- The added engineering time and cost associated with more advanced analysis techniques can often be easily justified by significantly reducing construction costs and schedules, however, this is not always the case. Important considerations that should impact analysis method decision making will be discussed.
- Seismic analysis and design criteria utilized by many jurisdictions may be out of date and in need of revision to maximize the value of bridge seismic engineering projects.
- Ongoing research into shallow rocking foundations, with potential future impacts, will be examined.
- Currently available seismic analysis software tools will be compared and discussed.

Application of Performance Based Earthquake Engineering (PBEE) to Caltrans Ordinary Standard Bridge Design

Yeo (Tony) Yoon • *California Department of Transportation*
Toorak Zokaie • *California Department of Transportation*

Under Performance Based Earthquake Engineering (PBEE), new and existing bridge structures are analyzed to identify/quantify seismic performance in terms of vulnerability level, post-earthquake repair costs, and functionality which are meaningful measures to owners and stakeholders for their decision making. PBEE has four distinct stages: Hazard Analysis, Structural Analysis, Damage Analysis, and Loss Analysis.

This presentation will review the current status of development of PBEE application guideline for ordinary standard bridges which are commonly designed and constructed within Caltrans Right of Way. In addition, a practical example will be presented focusing on the fore-mentioned first three steps of PBEE, in order to show how the PBEE process can be practically applied to the seismic analysis of the ordinary standard bridges. This example will also show a comparison with current practice.

The first step, hazard analysis, will explain the generation and selection of a number of ground motion acceleration time histories whose damped elastic acceleration response spectra (ARS) are compatible with a target ARS for a seismic probability of exceedance (i.e. 5% in 50 years per Caltrans Seismic Design Criteria). The discussion regarding the input parameters for the ground motion generation and near-fault effects will be included in this step.

The second step, structural analysis, will explain the nonlinear time history analysis by preparing an idealized bridge model consisting of 3D elements of key components (such as columns, bent cap, abutment, and shear key). Their material (stress-strain) and section (moment-curvature) nonlinear constitutive models will be illustrated. Also, the type of damping, algorithm and integrator will be discussed briefly. A series of nonlinear time history analysis results will be evaluated using two engineering demand parameters (EDPs): column top displacements and curvatures within column plastic hinges.

The third step, damage analysis, will explain the estimation of seismic capacity compared to these EDPs. The column capacities are measured as either displacement or curvature capacities at desired damage levels, and are determined from push-over analysis made in longitudinal and transverse directions or moment curvature response at plastic hinges. Similarly, damage measures at other key components can be determined from their EDPs.

7D INSTRUMENTATION AND INSPECTION

Implementing the Next Generation of Bridge Inspection and Management Systems

Lee Tanase • *Bentley Systems*

State Departments of Transportation throughout the United States are making significant changes related to bridge inspection and management. This is being driven by technological advancements, new regulatory requirements, and increased public attention on infrastructure. Numerous state DOTs collectively overseeing over 100,000 bridges and culverts 3 meters or greater in length have recently implanted new software systems to streamline the approach toward bridge inspection and maintenance. Detailed routine information is collected on all bridges and additional information is collected on special and fracture critical structures. The state systems while tailored for each state's unique needs allow for unified entry and management of all bridge and culvert data across the entire agency. These systems also include advanced features such as scour channel profiles, gusset plate worksheets, and bearing measurement forms, interactive review process, maintenance/work orders, and prioritization schemes.

Agency personnel, private consultants, and local agencies are able to utilize the systems via secure web connections and in the field on tablet and laptop computers. Multiple personnel on fracture critical inspection teams can simultaneously collect information on different parts of a bridge and merge the data together into a single report on the server. The systems also manage the hundreds of pictures taken on large bridges and directly link to appropriate location (bearing, pier, or other component). The system frameworks serve as the one-stop bridge information portal and will also integrate with the new AASHTOWare BrM 5.2 software with multi-objective analysis and revised deterioration modeling. Numerous examples of software systems will be presented along with the detailed best practices from each state agency.

Economics of Infrastructure Health Monitoring or at Your Discretion?

Brian Westcott • *Intelligent Structures Inc.*

The cost of managing an inventory of bridges can be significantly reduced by deferring replacement of bridges using the combination of testing and structural health monitoring (SHM). In the US it is estimated there are 63,522 structurally deficient bridges out of a total bridge inventory of 607,751. A surprisingly small number have been placed there based on structural testing. Bridges that are structurally tested are often, but not always, found to have a higher load capacity than that estimated by analysis alone [1]. The underestimates may be due to the prudent application of safety

margins due to uncertainty about materials and construction. It may also be due to over simplified structural assumptions, inaccurate modelling of boundary conditions and ignoring the load bearing capacity of "non-structural" elements. However, once results from testing are available, it is the updated estimate of the capacity that is the most appropriate to use. One can conclude that the replacement many bridges could be deferred through testing to ensure capacity and the application of monitoring to ensure ongoing capacity and safety. The economic return of deferring replacement is very high as the yearly borrowing cost for even modest structures exceeds the cost of typical SHM system. In this work, a bridge testing and SHM policy was used for model calculations on an inventory of bridges. Based on an annual model budget of $100 million for structurally deficient bridge construction and $5 million for construction per bridge. In this paper we will present cost simulations over ten years that utilize a policy of testing, monitoring or replacement to maximize the utilization of the bridge assets. The simulations predict application of SHM could reduce a ten year $1 billion budget by over $600 million. Further the analysis will be extended to include an assessment of how this would apply to the bridge inventory in California and Nevada.

Macro vs Micro: The Future and Past of Bridge Instrumentation

Shaun Dustin • *Campbell Scientific*

What is the true value of instrumentation for bridges and related structures? Over the past decade, instrumentation has been incorporated into many high profile structures to varying effect. Has it lived up to the promise that researchers, designers, suppliers, and contractors have represented? Is it useful? What place does it have in a code-based design paradigm? If instrumentation has a place, what is it and how can Owners derive value from the investment in monitoring? Is there a way to develop a consistent approach to system design, data collection, and data management? The paper reviews these questions in the light of specific case studies and proposes a process for discussion that may be useful for DOTs considering instrumentation programs.

8A BRIDGE JOINTS AND BEARINGS

High Load Multirotational Bearings for the Sellwood Bridge

Ron Watson • *R.J. Watson, Inc.*

The Sellwood Bridge replacement project is an engineering marvel in that the 88 year old 3400 ton, 1100 foot long existing steel truss was moved 66 feet to the north to facilitate the construction of the new steel deck arch. This is the largest bridge project in the history of Multnomah County who received a low bid of $307.5 million from the joint venture of Slayden Construction Group and Sundt Construction. The new bridge will have three arch spans of 385, 425 and 465 feet respectively and will require some sophisticated high load multirotational bearings.

The design engineer, T. Y. Lin International, completed an exhaustive search for the best device to accommodate the loads, movements and rotations of this complex structure and decided to use disk bearings based on their long history of outstanding performance on many other arch structures.

Disk bearings were developed in the early 1970's as a low cost superior performance multirotational device compared to pot and spherical bearings. The key component of the disk bearing is the polyether urethane load and rotational element. Polyurethanes have tremendous compressive strength and outstanding weathering properties. In addition the material will remain flexible and stable from -70 to + 120 degrees centigrade. This presentation will cover the development of the disk bearing and highlight some of the features that made disk bearings the logical choice for the Sellwood Bridge Project.

Seismic Retrofit of the Nenana River Bridge

Travis Arndt • *Alaska Department of Transportation & Public Facilities - Bridge Design*

Originally constructed in 1970, the Nenana River Bridge is an approximately 900 foot, three span steel deck truss crossing of the Nenana River. As part of a 3R project in 2014, the bridge underwent a seismic retrofit. The bridge was originally constructed using rocker bearings at the abutments and atop 100 foot tall, hollow concrete piers. The rocker bearings were replaced with friction pendulum bearings. The presentation will focus a portion on the reasons behind the bearing change and their design, but primarily focus on the construction aspects of the bearing change, subsequent issues the arose once the bearings were installed and the modifications that were needed to stabilized the bridge.

Innovations in Bridge Engineering

Iman Talebinejad • *SC Solutions*

This study pertains to the numerical and experimental studies of an unprecedented multi-movement rail joint designed for the Homer M. Hadley Memorial Bridge located in Seattle, Washington. The bridge carries the westbound and reversible lanes of Interstate 90 across Lake Washington and is the widest and fifth-longest floating bridge in the world. As a part of the light-rail extension program, Sound Transit proposed to install light-rail tracks on the bridge. The floating portion of the Hadley Bridge is constantly moving due to daily and seasonal changes in lake level and temperature, wind and wave action, and roadway vehicle traffic. These movements are accommodated with a novel rail joint, the Curved Element SUpported RAil (CESuRa). Following the initial design and analyses of the CESuRa, a set of tests were performed at the University of Washington to verify the behavior of different components of the rail joint. Based on the findings from the component tests and numerical analyses of detailed finite element model of the floating bridge including CESuRa, full-scale in-track testing of a prototype CESuRa was designed and performed to confirm the performance criteria. The full-scale experiment was also simulated with a FE model for calibration. The numerical results including train wheels reactions, CESuRa movements were compared with those of physical tests.

This paper will describe and discuss the analytical methods used to evaluate behavior of the Track Bridge with regards to the CESuRa and light rail vehicles response. The analytical results will be compared with full-scale testing results.

8B RAIL AND RETAINING STRUCTURES

Bridge Design and Construction

Yuhe Yang • *Parametrix*

Design Optimization for Sound Transit's Light Rail Lynnwood Link Extension

Significant Changes for Design and Construction Costs of Earth Retaining Structures Caused by Changes in RRecent AASHTO LRFD Design Criteria (2007 through 2014)

Ahilan Selladurai • *AECOM Transportation*

Earth retaining structures are a major element in infrastructure projects. They have been designed and constructed based on allowable stress design (ASD) criteria 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 and experience for engineers and designers in recent years. 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. 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 Cellular Concrete Fill to Mitigate Railroad Bridge Approach Settlement

Nathan Johnson • *Kleinfelder*
Moises Arzamendi • *Kleinfelder*

Budget constraints and urban congestion demand the use of innovative materials and methods to solve contemporary engineering challenges. Additionally, the design tools of today facilitate advanced analysis to gain confidence for their application. The San Diego River Bridge Double Track Project, delivered using CMGC procurement, is a critical piece of double-tracking for the Los Angeles – San Diego – San Luis Obispo corridor, the second busiest commuter rail corridor in the United States. Additionally, it is a critical economic link for freight rail traffic to the Port of San Diego. Three agencies have interest in the double track project and served as active stakeholders with varied responsibilities and bias of interest: the right-of-way owner (Owner) for property related issues such as drainage and damage to adjacent property; the Metropolitan Planning Organization (MPO) for completing the job within prescribed scope, schedule, and budget; and the maintainer/operator (Operator) for a safe and maintainable railroad. The needs of all stakeholders must be met, and particular scrutiny can be placed on innovative methods to solve engineering challenges.

The project requires embankment fill be placed along an approximate 1500 foot length north of the San Diego River bridge approach to build a second main track (MT2). The proposed embankment, approximately 15 feet high would be placed upon alluvial and estuarine deposits. Constraints related to this embankment include the following:

- Limited right-of-way width between existing mainline track and adjacent buildings require retaining structures.
- Retained embankment is underlain by soil with high potential for seismic induced liquefaction (approximately 40 feet deep) for the design event. Settlements and lateral movements are estimated as 7 inches and 10 to 20 inches, respectively or the survivability limit state.

- Retained embankment is underlain by soil with high susceptibility to surcharge settlement caused primarily by clay and silty clay deposits located approximately 30 to 40 feet below grade. Surcharge settlement was estimated as 5 inches below the track and approximately 2 inches for adjacent buildings.
- Groundwater is shallow, approximately 10 feet below the base of embankment.
- Several sensitive franchise and drainage utilities are buried below the proposed embankment
- Traffic through the rail corridor must be maintained except for a few weekend closures throughout the year.

Several solutions were reviewed during type selection for the proposed rail embankment including: traditional fill with ground improvement, elevated track structure, purchasing of adjacent right-of-way and allowing settlement, and lightweight fill with select ground improvement. Although lightweight fill may be the least common solution for heavy rail, it proved to be the most reasonable with respect to minimizing settlement risk to adjacent property, constructability, maintenance of traffic, seismic resistance, capital cost, utility protection, and maintenance. The preferred solution was to balance embankment loading with over-excavation of existing fill using lightweight fill. Both lightweight cellular concrete fill (LCCF) and geofoam were assessed, and LCCF was preferred due to chemical resistance, uniformity, and precedent for supporting heavy rail loads. The fill would be detailed similar to a mechanically stabilized earth wall with straps and facing.

LCCF has been used previously throughout the Western USA, however, only two cases, which had some differences to the proposed project had been identified as directly supporting heavy rail loads. These, combined with other highway and LRT lightweight fill projects were reviewed in conjunction with available design guidance to work with the stakeholders and develop project specific criteria. Criteria included requirement for a 100-year service life for the LCCF system, and conservative geotechnical design methodology. Three-dimensional settlement analysis was performed and used to develop ground improvement requirements beneath the LCCF. The ground improvement was necessary to help minimize static settlements since the water table and staging precluded full balancing of loads. Through the CMGC process the LCCF geometry and phasing placement was optimized to reduce shoring and impacts to rail traffic. Also, the design team and CMGC worked together to optimize ground improvement methods and associated performance specifications.

8C BRIDGE SEISMIC DESIGN

Base Isolating the New NY Bridge

Nick McDowell • *HDR Engineering*
Red Bush • *HDR Engineering*

The New NY Bridge, designed for a 100-year service life, will replace the operationally deficient existing bridge that carries more than 138,000 vehicles each day. A seismic isolation strategy using Triple Friction Pendulum Bearings was implemented for the approach spans to ensure essentially elastic structural performance of the piers during a high-level seismic event. Nonlinear time history analyses were performed using ADINA, where large displacement element formulation and friction contact surfaces explicitly model the friction pendulum bearing assembly. A total of 580 friction pendulum bearings were modeled between the eastbound and westbound global models. This presentation will provide an overview of base isolation as a seismic design strategy and discuss the procedures and techniques implemented in the global structural analysis models. Additional discussion will address large model organization; tools for developing finite element components, such as hysteretic bearing properties, foundation properties, and boundary conditions between the approach and main spans; and finally, the workflow and iteration between the global analysis, superstructure, and substructure design teams. A comparison will be made between results of two independent models: one using RM Bridge to perform a multi-modal response spectra analysis; the second, using ADINA to perform a nonlinear time history analysis.

2nd Street Connector, Gateway to Historic Sacramento

Ali Seyedmadani • *Parsons Brinkerhoff*

The I-5 Riverfront Reconnection project in City of Sacramento aims to create connectivity across the depressed I-5 freeway to major point of interest along the Riverfront. Historic Sacramento and waterfront adjacent to Capitol Mall houses the California Rail Road Museum in the State Park and is a major tourist attraction in the region. The 2nd Street Bridge will connect the Capitol Mall Bridge to Historic Sacramento District, creating a "front door" to historic Sacramento and waterfront. The project stakeholders were interested to have a bridge structure that would blend into the surrounding area and visually not be seen as a "bridge". Due to limited right-of-way this bridge had to be designed to overhang the I-5 freeway retaining wall system "boat section". In addition, due to poor soil condition, being adjacent to the Sacramento River and seismic performance concerns a robust finite element analysis was required to design the foundation system for this bridge. The engineering challenges had to overcome the soil liquefaction concerns, impact to the I-5 retaining wall system, as well as the stakeholder's visual/ aesthetic concern with the bridge. Ultimately, isolation casings and straddle bent were utilized to accommodate and control the structure displacement demands during the seismic event. In addition, brick fascia, and false walls were used to eliminate the visual openings of the bridge and provide visual and noise mitigation for the I-5 freeway while accomplishing the visual objectives.

Seismic Design of Walnut Avenue Overpass

Ali Rejaie • *HNTB*

San Francisco Bay Area Rapid Transit's (BART) WSX alignment crosses the active Hayward Fault, CA at two locations, one directly southeast of Walnut Avenue (the Walnut Avenue Overpass site) and one Northwest of Washington Boulevard. The Hayward fault is one of the primary active faults in the San Francisco Bay area, and is considered capable of generating an earthquake large enough to result in surface rupture and damaging structures overlying the fault trace. It is estimated that during a fault rupture event, ground displacements up to 4.2 ft in the horizontal direction and up to 0.8 ft in the vertical direction may occur. Additionally, fault creep can generate relative horizontal ground displacements of 0.20 inches/year at the fault trace.

The challenges described above drove the design of the Walnut Ave Overpass Structure. The overall design philosophy was to provide a simple, highly predictable load path that allows the design of components to be almost independent of each other. The superstructure consists of a pair of simply supported single track CIP post-tensioned concrete through girders supported on elastomeric bearings. The simple spans allow for the horizontal fault movement to occur without imparting additional forces to other bridge components. The girders are also designed to resist additional torsional demands from the expected vertical fault rupture offset.

The girders are supported on short-seat abutments on spread footings to minimize the potentially unpredictable behavior of other foundation types. The spread footings are founded on MSE walls. The MSE mass underneath is detailed and designed to behave as a rigid block as it slides over the ground during a fault rupture event. To reduce the sliding forces between the MSE block and the underlying soil, a "transfer-slab" will be poured underneath the MSE block in the area of the fault trace. The result is that the horizontal fault rupture will be isolated to the transfer slab level below the MSE mass and will reduce or eliminate the vertical and horizontal displacements at the superstructure level. Additionally, both abutments are designed with over 6 feet long seat lengths which exceed the expected seismic displacement for fault rupture. This provides an additional level of safety and redundancy, should the slip plane not perform as anticipated.

BART seismic design specifications for bridges has the goal to ensure safety and to provide post-earthquake operability by limiting strains, deflections and damage such that they are capable of being returned to service within a reasonable amount of time after the Design Basis Earthquake (DBE) with only minor repairs or shoring. Simplicity and redundancy were drivers of a design capable of accommodating the seismic demand requirements. By decoupling each component's function and designing each element independent of each other, a highly predictable load path and displacement behavior was achieved.

8D LOAD RATING

Live-load Distribution Factor for Reinforced Concrete Bridge Girders

Kash Nikzad • *TranTech Engineering, LLC*

The live-load distribution factor is normally obtained by using AASHTO equations. The AASHTO equations for live-load distribution factor are obtained from a parameter study of different girder spacing, span length, skewed angle and slab stiffness. It has been shown that the AASHTO code live-load distribution factor is conservative for bridges with large span-to-depth ratio.

The finite element method can be used to compute the live-load distribution factor as follows: The finite element model is created in CSiBridge program; for each load case, the moment in each girder and the moment (and shear) of the entire superstructure are recorded; the live-load distribution factor is obtained by dividing the maximum girder moment (and shear) by the moment of the superstructure.

This study evaluates the flexural and shear live-load distribution factor for reinforced concrete bridges. The AASHTO code live-load distribution factor is compared to that of the finite element method. A three-span reinforced concrete girder bridge is used to evaluate the live-load distribution factor. Twenty bridge configurations are used to investigate the effects on the live-load distribution factor of bridge type (i.e., diaphragm, continuity and skew) and load type (i.e., axle width).

The numerical results showed that:

1. The live-load distribution factor calculated from AASHTO LRFD Specification is conservative. In some configurations, the live-load distribution factor obtained from AASHTO LRFD is 20% greater than that from finite element model.
2. End diaphragm reduces the live-load distribution factor while intermediate diaphragm has no effect on the live load distribution factor.
3. Distribution factor decreases with skew angle.
4. Distribution factor decreases with axle width.

An Innovative Procedure for Load Rating of Suspension Bridges

Hassan Sedarat • *SC Solutions*
Iman Talebinejad • *SC Solutions*
Alexander Kozak • *SC Solutions*
Joyce Lee • *SC Solutions*
Farid Nobari • *SC Solutions*
Alex Krimotat • *SC Solutions*

Over two hundred million trips are taken daily across structurally deficient bridges in the nation's 102 largest metropolitan regions, per 2013 ASCE Report Card for America's Infrastructure. The average age of the nation's 607,380 bridges is currently 42 years. The nation has an entire generation of bridges, constructed in the 1950s and 1960s, that need major repair or replacement. To address this problem, National Bridge Inspection Standards (NBIS) mandates bi-annual inspection. Load rating of bridges is required by the Department of Transportations (DOTs) across the Nation. While general guidance is available in the American Association of State Highway and Transportation Officials (AASHTO) manual for typical and simple bridges, no general guidance for load rating of complex bridges is available in current civil engineering practice. Therefore, more complex procedures must be developed and used for the actual determination of the load rating of these bridges. In this paper an innovative procedure for load rating of suspension bridges is presented, which provides a framework for the rating of complex bridges. It eliminates the uncertainties in the calculation of dead load, live load or unknown overweight vehicles, distribution factor, increase in traffic volume, impact loads, and vehicular speed. The component-specific demands will be obtained from measured displacements at limited selected locations, and will be compared with the resistance or state of structure in its healthy condition (baseline). The proposed procedure will be applied to the Alfred Zampa Memorial Bridge, also known as the New Carquinez Bridge, which connects the cities of Vallejo and Crockett in California.

Snake River Bridge Load Test: Addressing Bridge Management Issues.

Brice Carpenter • *Bridge Diagnostics Inc.*
Shanon Murgoitio • *Idaho Transportation Department*

The Snake River Bridge is a three-span, continuous twin-girder/twin-stringer structure that carries two lanes of SH-52 traffic over the Snake River between Idaho and Oregon in Payette, ID. This fracture critical structure serves important agricultural and fire protection routes for the local community. Both Idaho and Oregon transportation departments (ITD and ODOT) used conventional AASHTO load rating methods and found that this bridge did not have sufficient strength to safely carry local harvest transport and fire protection vehicles. Rather than increase user costs and hinder the community's economy and fire response time; the bridge owners decided to further verify the structure's live-load capacity through diagnostic load testing and field-verified load rating. An in-depth load testing program was performed and subsequently used to calibrate a finite-element model (FEM) of the structure. Once the structure's response behavior was accurately simulated by the optimized FEM, this model was used to calculate accurate load ratings. Through this refined analysis, it was found that this fracture critical structure distributed vehicular load much better through its deck and floor system than previously assumed using typical AASHTO distribution factors. These results allowed the bridge owners to remove the structure's posting and allow local legal truck loads to utilize the bridge. This case study shows how bridge owners used evaluation tools at their disposal, including diagnostic load testing and field-verified load rating techniques, to solve a bridge management problem.

9A BRIDGE DESIGN AND CONSTRUCTION

SR-89 Hell Canyon Bridge

Mike Morrison • *ADOT*

Hell Canyon Bridge is located on State Route 89 in Yavapai County, AZ at MP 345.70 between Prescott and Ashfork and is currently open to traffic. The existing 585′-6″ steel deck truss bridge was constructed in 1954 by the Arizona Highway Department. Hell Canyon Bridge has a clear roadway width of 30′-0″ that accommodates two 12-foot lanes with 3′-0″ shoulders on each side. F-Shape barriers were added to the bridge in 1984 replacing the original curb and railing.

The Hell Canyon Bridge project is located within the east-central portion of the uplifted structural block referred to as Big Black Mesa. The local site geology is dominated by massive volcanic lava flow deposits of basalt that cap a thick sequence of the Mississippian Age Redwall Limestone formation. The bridge spans a rugged V-shaped canyon with very steep to near vertical slopes along the north side. The bridge height measured from the surface of the existing deck to the lowest point of the canyon is approximately 144 feet.

Problem: Recently, the existing bridge deck began experiencing problems. Currently, the overall rating for the deck is poor. The bridge deck top is rated as serious. The deck wearing surface has a high density of transverse cracks. There are numerous spalls and patches throughout the deck. The deck undersurface has transverse cracks with efflorescence and spalls with exposed reinforcing in localized areas. An emergency repair was made to the bridge deck in 2013 after a 6-foot portion fell away. The bridge had to be closed to traffic during this period.

Solution: Because of poor deck conditions and narrow shoulders, alternative options were considered including bridge rehabilitation by widening and replacing the existing superstructure as well as complete bridge replacement. The replacement option considered various superstructure types and configurations. ADOT decided to replace the existing bridge with a continuous steel plate I-girder bridge on a new roadway alignment. This project is currently in construction. The new alignment will be established 46′-0″ to the east of the existing roadway allowing the new bridge construction to occur in one phase. Two lanes of traffic can be maintained along the original alignment, with intermittent periods of one-lane signalization required at the alignment tie-in points on the north and south ends of the project.

With such steep slopes, accessing the canyon will prove a challenge. Access roads will be provided at both ends of the bridge. These roads need to be wide enough to allow cranes adequate room to maneuver around several switchbacks. Brief closures will occur during the erection of the steel girders allowing cranes the option of lifting girders directly from transporting trucks positioned on the existing bridge. The existing bridge will be removed when the new bridge is complete and open to traffic. The new bridge will be utilized during the removal of the existing bridge superstructure. All access roads will be covered over and the canyon will be restored at project completion. The $14 million project is scheduled for completion by the fall of 2016.

Design and Construction of an International Airport Bridge between California and Mexico

Paul Morel • *Kleinfelder*

The San Diego-Tijuana Cross-Border Facility Pedestrian Overcrossing (POC) will provide a direct connection between the new Cross-Border Facility terminal building in the U.S. and the new extension of the Tijuana Airport terminal building in Mexico. It will allow ticketed passengers flying into or out of the Tijuana Airport to circulate across the international border between the two buildings. The bridge consists of a pair of steel through-trusses, approximately 390 feet long with 3 simply-supported spans ranging from approximately 110 feet to 150 feet. The overall bridge section is approximately 37 feet wide and 20 feet high with two fully enclosed, physically-separated corridors (northbound and southbound). The POC is supported on four reinforced concrete pier walls ranging from approximately 19 to 25 feet in height, and cast-in-drilled-hole concrete piles. The bridge was designed per the AASHTO LRFD Bridge Design Specifications, AASHTO LRFD Guide Specifications for the Design of Pedestrian Bridges, AASHTO Guide Specifications for LRFD Seismic Bridge Design (for the superstructure) and Caltrans Seismic Design Criteria (for the substructure).

The bridge alignment was selected in collaboration with the Customs and Border Protection agency to maintain security across the international border. The end supports (Bents 1 and 4) are located as close as structurally possible to the buildings on the U.S. and Mexican sides, respectively. Bents 2 and 3 are located in-line with the existing secondary (northern) and primary (southern) border fences, respectively. Inside the bridge, the passengers in the two corridors will circulate in opposite directions, with no visibility between corridors. The visibility of passengers from the outside of the bridge will also be restricted by an architectural facing on the exterior of each truss.

Aesthetics and functionality were a major consideration for this privately financed and operated project and were determined by the project architects and ownership in collaboration with the structural engineering team. The bridge exterior wall facing consists of a combination of aluminum and fritted glass panels. The corridors feature air-conditioning and moving walkways in the two longest spans. The POC also features a polished concrete floor, an acoustical ceiling, power and fiber-optic data cabling, sprinklers, smoke vents, lights, speakers and security cameras. On the U.S. side, the new Cross-Border Facility building will include shops, restaurants, parking and ground transportation.

The project required many local and federal permits and approvals in both countries, including a Presidential Permit in the U.S. and a permit from the Department of Transportation in Mexico. The in-progress construction, which follows Caltrans Standard Specifications, has required bi-national and bilingual coordination between the design team and the Contractors on the U.S. and Mexican sides. The project is expected to be completed in the fall of 2015.

Seismic Retrofit and Reconstruction of the Historic Georgia Street Concrete Arch Bridge

Ebrahim Amirihormozaki • *Kleinfelder*
Nathan Johnson • *Kleinfelder*

Locally owned bridges are in great need of rehabilitation, retrofit, and replacement throughout the western United States. Such solutions often require balance of stakeholder support considering capital funding, life-cycle cost, environmental impacts, and public safety. Design for the historic Georgia Street Bridge and Walls (Georgia Street Bridge) is a prime case study to demonstrate a balance that can be expected for aging bridges reaching their life expectancy.

Constructed over 100 years ago as "The Gateway to eastern San Diego", the Georgia Street Bridge provides a grade separation linking mid-city San Diego to Mission Bay. The substructure is three 3-hinge arches with integral spandrel columns supporting a two-frame superstructure. The superstructure includes three discontinuous floating slabs at mid-span and at the abutments. Abutment walls continue into anchor-block retaining walls to create an approximate 700-foot-long grade separation below the bridge. The structures are badly deteriorated with cracks and spalls throughout the wall face, bridge deck, spandrel bents, and barrier rails. The deck and supporting arches lack continuity which would lead to collapse during the design seismic event. Columns and arch elements are not detailed to resist shear forces and would be subject to non-ductile failure. Both abutments and retaining walls are significantly inadequate to resist sol pressures from earthquake loading.

Since the early 1990s extensive studies of the bridge and walls have been performed by Caltrans and the City of San Diego. The preferred strategies to replace this bridge were met with strong opposition by the community. The current team was retained in 2010 to develop a retrofit and rehabilitation strategy that would retain historic character, provide a safe structure for the public, and extend the service life by at least an additional 50 years. As a result of countless stakeholder and project development team meetings, a preferred alternative has been selected and designed.

The entire superstructure and spandrel columns will be replaced with identical geometry but will meet modern service and seismic demands. The arch ribs will be retrofitted to increase their shear capacity and service life using hydro-demolition to remove cover concrete, adding new welded ties, and replacing the cover concrete with a self-consolidating concrete mix containing glass. Internal shear walls will couple the arches and superstructure in the longitudinal direction. Abutment soil improvement will help prevent arch rib uplift. The abutment and retaining walls will be stabilized using ground anchors and soil anchors tied to new facing. The roadway below will be lowered approximately two feet to improve vertical clearance.

The anticipated SR after construction is expected to be improved from 44.8 to 76.7, and the SD flag will be removed. The project delivery team was successful in overcoming design and constructability challenges while meeting needs of all stakeholders. The project is scheduled for construction in mid-2015.

9B BRIDGE ANALYSIS

Effect of Curved Alignment and Skewed Supports on Bridge Response by Lucas Miner, Benjamin Fell, and Toorak Zokaie

Lucas Miner • *Drake Haglan and Associates*

Bridges with tight curvature in plan and skewed supports are becoming more common as engineers are asked to design bridges to conform to space-efficient roadway layouts. However, simplified 2D models currently used in practice may not capture the structural behavior of these bridge configurations and may result in inaccuracies in the design. For example, several single span bridges on tight curves have experienced uplift at corners, and exceedingly large reactions at other corners which were not predicted by simplified analysis. In other cases with multi-span bridges, the column forces were overestimated resulting in excessive rebar or stiffer columns which tend to increase the seismic design loads. This project quantifies the effect of curved alignment and support skew on bearing reactions and substructure demands to allow for more efficient and safer design of bridge foundations.

The presentation will provide analysis results from a parametric study investigating the effects of abutment skew and horizontal alignment curvature on bridge reaction forces, superstructure shear and moment, and column moments. Over 800 single-span box girder bridges were modeled using three-dimensional finite element analysis software. The effects of skew angle, curve angle, and a coupled skew-curve effect on abutment reactions in the obtuse corners of single-span box girder bridges were found to be significant.

These results are compared with state-of-the-art bridge design practice and AASHTO-LRFD specifications that provide guidance on designing bridges with skew and horizontal curvature. Interestingly, the foundation results demonstrate that the obtuse corner reaction forces are greatly influenced by the bridge aspect ratio across a wide variety of skew and curve angles. Furthermore, the horizontal alignment curvature has a large effect, even at very small alignment central angles. Moreover, the effect of skew angle is shown to be partially dependent on bridge curvature; although this coupling of the skew and curve effects is minimal at small skew angles. The bearing stiffness was also varied, which had a large effect on the reactions of skewed and curved bridges. Empirical equations for skew and curve correction are proposed and additional research is recommended. Superstructure demands on the other hand show that the effect of torsion on girder shear cannot be ignored in some cases and simple procedures are presented to capture torsional effects when a spine model is used for design. Column flexure demands can be highly overestimated, especially in single column bents when a spine model is used for analysis. These flexure demands have a direct effect on the size of the foundation and unnecessarily increase the cost.

Live Load Distribution on Bridge Abutments

Toorak Zokaie • *Caltrans*
Amir Malek • *Caltrans*
Amir Rahbari • *Caltrans*

When designed according to LRFD, bridge abutments are designed to withstand live load, nevertheless there is a lack of common and unified practice on how live load is distributed on the abutment, its components, and the foundation. There is also no specific guidance by the AASHTO LRFD bridge design specifications on this topic. Most common practice is to distribute the live load reaction from the superstructure uniformly along the abutment length. This simplification ignores several key factors including stiffness of the substructure and its nonlinear nature, type of foundation (pile or spread footing), effect of concentrated wheel loads near abutment, and the impact due to the height of the abutment, each of which could affect the maximum soil bearing pressure or the pile load. As a result, the design could be unconservative, not meeting code-intended loads, or conservative, leading to higher cost.

To arrive at an acceptable simple and efficient procedure for analysis of abutments under live load an analytical study has been initiated. The study includes finite element modeling of several bridges and abutment types for flexible and rigid foundations to evaluate various commonly practiced methods, and select or develop a simplified procedure for design that delivers acceptable accuracy. The following factors have been considered in this study:

- Abutment types (Short and tall cantilever and diaphragm)
- Abutment width (number of lanes)

- Foundation types (deep and shallow)
- Superstructure type (box-girder and I-girder)
- Span lengths (80 ft to 240 ft)
- Various soil types (rock, medium and dense sand, and soft and stiff clay)
- Nonlinear soil or pile stiffness

It is anticipated that the outcome of this study could serve as a basis for more accurate analysis of abutments for live loads. This would result in a more consistent design practice, bringing a more uniform level of safety to bridge abutments while minimizing costs.

Impact of Air Pressure Testing on Post-Tensioned Anchorage Ducts

Brett Allen • *Eclipse Engineering*
David Sanders • *University of Nevada, Reno*
Michael Taylor • *Nevada Department of Transportation*

Our seismic retrofit and rehabilitation PS&E for both the land piers and the cable supported bridge involved the evaluation and strengthening of the anchorages, replacement of some of the wind cables and replacement of some of the stiffening truss system. The project also involved installation of a modern walkway with cable restraint system. We mitigated the construction access issue by proposing the use of aerial high lines for lifting and delivering materials and supplies. The project design was subject to peer review by the Bureau of Reclamation and the construction contract was awarded in April 2015 and will be completed in June 2016.

9C BRIDGE DESIGN AND CONSTRUCTION

Accelerated Scheduling for I-90/Cliff Ave. Bridges

Hadly Eisenbeisz • *South Dakota Department of Transportation*

Construction of a single point urban interchange with two 374′ steel plate girders can be a challenge to complete in one South Dakota Construction season. The DOT and contractor took several steps to expedite completion of the interchange in one season while keeping it open to traffic. Pre-purchasing girders, self- consolidating concrete, pre-tied reinforcing steel and pre-cast sleeper slabs were just a few of the techniques used to accelerate construction. The successful completion of the interchange was a direct result of the accelerated scheduling and construction techniques used by both the DOT and contractor.

Seismic Retrofit of Ogden Siphon Pipe Suspension Bridge

Mark Reno • *Quincy Engineering, Inc.*

The Ogden Siphon's original pipeline and structural supports were designed in 1936 by the U.S. Bureau of Reclamation and consists of 1,044 feet of 31.25 inch diameter pipe supported by four 1.50 inch diameter main cables (with two 1.125 inch diameter wind cables) spanning 360 feet across (and 200 feet above) the canyon floor and highway; structural land supports consists of braced frames and foundations spaced 40.0 feet on center. The pipeline delivers water from the Pineview Reservoir, along Highway 39, across Ogden Canyon, to local water users for residential irrigation, from April to October only.

The design process was initiated as a Construction Manager/General Contractor (CMGC) alternative delivery process. As such, the design team refined the design to increase efficiencies and reduce risks while focusing on constructability issues. However, the CMGC estimates revealed that a replacement scheme had more value than the retrofit scheme. Ultimately, the Owner and CMGC firm could not reach a price agreement, so the Owner delayed the project for one year and readvertised a bid-build project.

The pipeline is owned by the Bureau of Reclamation, but is operated and maintained by Pineview Water Systems, in Ogden, UT. As the owner and the pipeline water users would require continuous water service after a major wind or seismic event, as well as during construction of the new structure, Quincy staff had to develop a project specific design criteria that drew from multiple codes such as ASCE 41, ASCE 7, AISC 360, ACI 318 and AASHTO, as there is no single code for this type of suspension bridge and cable. The site is prone to high wind and seismic loads and required extensive research to develop the correct site specific design criteria. Additionally, the height/location of the structure presented a construction access challenge.

Quincy was retained in 2012 to provide a condition assessment analysis and to design retrofit measures to extend the structure's service life to 50+ years. Quincy successfully developed the site specific design criteria as well as unique construction methods.

Our seismic retrofit and rehabilitation PS&E for both the land piers and the cable supported bridge involved the evaluation and strengthening of the anchorages, replacement of some of the wind cables and replacement of some of the stiffening truss system. The project also involved installation of a modern walkway with cable restraint system. We mitigated the construction access issue by proposing the use of aerial high lines for lifting and delivering materials and supplies. The project design was subject to peer review by the Bureau of Reclamation and the construction contract was awarded in April 2015 and will be completed in June 2016.

Our presentation will summarize the decision process utilized by the Quincy design team in determining the most effective means to develop the specific design criteria and retrofit measures that allowed the structural steel framing and the pipe to interact appropriately with the flexible suspension cables, as well as the selected approach for construction mobilization in this type of high mountainous terrain.

I Didn't Know They Could Do That! Capabilities and Design Considerations for Flexible Buried Bridges

Joel Hahm • *Big R Bridge*

Structural plate buried structures have been in use for over 80 years. These types of structures started out as a more robust alternative to traditional culverts for use in hydraulic and minor crossings where culverts could not meet flow and size requirements and/or where bottomless structures were needed. Over the past 40 years there has been a significant increase in the use of structural plate as buried bridges in hydraulic crossing and grade separation applications where 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 security through redundant systems, improved aesthetics through the use of a wide variety of end treatments, environmental advantages, ABC benefits, and lower maintenance and inspection costs compared to traditional bridges. Flexible buried bridges are an attractive alternative to many low to medium span traditional bridges.

Design of structural plate buried bridges is covered in Sections 12.8 and 12.9 of the current AASHTO LRFD Bridge Design Specifications. Although structural plate buried bridges have been in use for a long time and provisions for their use as flexible buried bridges have been fully incorporated into the AASHTO LRFD design and construction specifications, many engineers are not familiar with the range of capabilities, key design inputs, and project considerations, as well as the concept of soil-structure interaction. As a result, many engineers are not sure where to begin and buried bridges are often not considered for bridge applications where they may be the best crossing option. While there are some design similarities with culverts & traditional bridges, the level of analysis and inputs involved with design of buried bridges is often more detailed depending on the structural plate corrugation profile and project requirements. In many cases, the design process can be more rigorous than design of traditional bridges but will also allow more economy by customizing the structure design to site conditions and construction practices. The goals of this presentation are to outline the design process for buried bridges, highlight key design inputs, and show design advantages of using flexible buried bridges as an alternative to traditional bridges. This will include an introduction to the AASHTO LRFD design requirements for buried bridges and include case studies. Among the specific topics to be discussed are design, materials, foundations, fabrication, load rating, construction, and maintenance.

9D BRIDGE INSPECTION

Vertical Clearance Measurements & Posting of VC Signs

Homer Saidi • *ADOT*

National Bridge Inspection Standards (NBIS), 23 Code of Federal Regulations (CFR) 650, Subpart C applies to all structures defined as highway bridges located on public roads. Public road is defined in 23 CFR 650.305 as any road or street under the jurisdiction of and maintained by a public authority and open to public travel. NBIS structures do not include railroad bridges, pedestrian bridges, and any other bridges that do not carry public traffic. Any structure that goes over a public roadway requires an under-record.

Traditionally, the bridge under-records are mainly composed of vertical and lateral clearances. These clearances have been measured by variety of methods such as measuring tapes and surveying rods with or without level. Later on, several other techniques were added such as hand-held ultrasonic and laser distance measurement devices as well as fixed point lidar techniques. More recently, the developments have shifted from fixed point to mobile units (laser-based point measurements in motion or Laser-radar cloud points) due to high cost of traffic control and public displeasure with detours or delays. These methods utilize mobile measurement units driving at normal driving speeds without delay or disturbance of traffic while recording laser based measurements on a laptop on board. The savings in measurement time and traffic control expenses should be balanced against the cost of data processing and instrumentation. There is another way to consider this task. Some DOTs use inspection teams with or without traffic control, complete or partial traffic control, outside resources as well as dedicated vertical clearance measurement teams. This paper deals with:

1. Cost comparison of several methods for a given set of structures (say 1000)
2. ADOT policy regarding vertical clearance measurement and posting VC signs
3. Presentation of a locally generated spreadsheet for calculation of VC related NBI codes N54 and N10 (under record)
4. Finally, a short presentation regarding application of potentially innovative technique which may be of significant value in point

Underwater Inspection of the Golden Gate Bridge: The Image of an Icon

Daniel Stromberg • *Collins Engineers, Inc.*

When it came time to inspect the Golden Gate Bridge below water, the Golden Gate Bridge Highway and Transportation District chose to incorporate a relatively new, two-fold approach, which included hands-on diving inspection in conjunction with state-of-the-art underwater acoustic imaging. With this approach in mind, in the spring of 2014 throughout two weeklong inspection periods, the iconic Golden Gate Bridge received an underwater structural safety inspection of its north and south tower piers.

To accomplish the task at hand, the Golden Gate Bridge District selected Chicago-based Collins Engineers, Inc. to provide the full gamut of the required underwater inspection and assessment services. The in-depth investigation included commercial diving operations and 3-D underwater imaging accomplished with a number of the latest advancements in sonar technology, all of which that was conducted and provided by Collins' in-house engineer-divers.

Ultimately, the use of leading edge 3-D imaging technology provided the Golden Gate Bridge District with high resolution imagery of the underwater construction and seabed topography to fully document the existing condition and configuration of the submerged bridge elements and surrounding channel bottom. Coupled with the 3-D imaging results was the detailed hands-on inspection and assessment of the submerged bridge construction by engineer-divers to collectively provide the District with a most comprehensive picture of the bridge's current state below the surface of the waters of the Golden Gate Strait.

Summary of Safety Inspection Practices for Bridges with Fracture Critical Members

Brian Leshko • *HDR Engineering, Inc.*

The Federal Highway Administration (FHWA) reviewed the current state of highway bridge inspection practices specific to bridges with fracture critical members (FCMs) based on a statistical sample (level of confidence of 80% and a margin of error of 15%) of 94 bridges from the National Bridge Inventory through a contract with HDR Engineering (HDR). Bridge inspection information for these 94 bridges solicited from 34 States was reviewed from May-August, 2012 by HDR staff as part of an independent review of the quality and sufficiency of the safety inspection practices of bridges with fracture critical members. HDR staff assessed various categories of bridges that were established to provide a mix of structure types and elements, and to consider both high and low traffic volumes. The team reviewed recent fracture critical inspection reports to gain a better understanding of how this important area of the bridge safety program is administered. A summary report was developed to detail the current state of FCM inspections, to summarize good practices and improvement opportunities identified during the review, and to provide a compilation of effective policies and practices for FCM bridges. Many states have developed excellent procedures to manage bridges with FCMs, and the FHWA wants to showcase these. It is also important to highlight improvement opportunities or areas of the program that require clarification. The information presented will also be useful for inspectors and inspection program managers who want to develop or improve their own procedures for bridges with fracture critical members.

K2 CLOSING KEYNOTE

The Tappan Zee Bridge Replacement (The New NY Bridge)

Kenneth Wright • *HDR*

The $3.1 billion Tappan Zee Hudson River Crossing (or "New NY Bridge") is one of the largest and most complex bridge projects currently under construction in the US. The project includes two parallel, 3.1 mile-long bridges crossing the Hudson River between Rockland and Westchester Counties, approximately 25 miles north of New York City. Each of the two bridges consists of a 1,200-foot cable-stayed navigation span with common foundations and diverging towers, along with a series of 350-foot continuous, steel girder spans supported on seismic isolation bearings.

The use of large-scale prefabrication is a critical part of the bridge design. Construction is being greatly accelerated through the use of large-scale precast concrete elements for the foundations, pier caps and steel superstructure. The Left Coast Lifter, one of the largest floating cranes in North America, with an 1,800 ton lifting capacity, is being used to install pre-assembled two or three girder groups, one full span at a time, which eliminates nearly all temporary falsework in the river, improves worker safety, and saves time and construction costs for operations on the water.

Primary structural components of the crossing are designed to provide a 100-year service life before major maintenance will be required. The design and construction is further complicated by poor foundation soils, moderate seismicity, ice loading, and the requirement for the bridge to accommodate a future third parallel bridge to carry dual-track railway traffic.

The presentation will describe important design considerations and provide an overview of the construction progress on the project.