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BRIDGES—CURRENT CHALLENGES AND EFFECTIVE SOLUTIONS

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K1 KEYNOTE

Gerald Desmond Bridge Replacement Project

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Construction of the Gerald Desmond Bridge Replacement Project (GDBRP) in Long Beach, California, is in the home stretch. The new bridge is located at the Port of Long Beach and consists of approximately 1.6 miles of bridge structure. The approach spans are made up of conventional cast-in-place box girders, while the main span over the back channel will contain California's first vehicular cable-stayed bridge. This signature structure will have a 1,000-foot main span and 500-foot back spans. Once built, the new bridge will be the second-tallest cable-stayed bridge in the U.S. with 515-foot-tall reinforced concrete towers, and have the highest vertical clearance of any cable-stayed bridge in the U.S. at 205 feet. This presentation will provide a general overview of the project and describe some of its key design and construction innovations and challenges.

The replacement bridge is founded on a total of 352 cast-in-drilled-hole piles that range in size from six to eight feet in diameter. The Contractor elected to use tip grouting at each of the piles in order to rely on end bearing, which resulted in an approximately 30-percent reduction in the pile length. More than 100 reinforced concrete columns of varying heights will support the superstructure, with the two towers supporting the main span featuring a hollow 515-foot-tall monopole design.

The signature cable-stayed bridge span consists of a pair of six-foot-deep steel edge girders with a box shape cross-section. Framing into the edge girders are variable-depth steel floorbeams with two lines of longitudinal stringers spanning between them. This floor system supports the full-depth precast concrete deck panels. The cross-section of the bridge has an out-to-out width of approximately 156 feet to accommodate three lanes in each direction and with emergency lanes on both sides (10 foot shoulders). Seismic demands on the main span will be dissipated with passive dampers at the towers and end bents.

The superstructure of the low-level approach spans was built using conventional falsework; however, the high-level approaches were built using two innovative Movable Scaffolding Systems (MSSes). This project is the first time in the State of California that an MSS was used to build bridge superstructure elements. Each MSS has a self-weight of 3.1 million pounds and was designed to support the formwork and wet concrete. With the load from the concrete, each MSS bore approximately seven million pounds, supported by brackets mounted onto the columns below it.

The main-span superstructure is being stick-built with help from stiffleg derrick cranes on the deck, and two 585-foot-tall tower cranes, which are the tallest tower cranes currently in use on any infrastructure project in the U.S.

In addition to an overview of the key design and construction elements of the bridge, this presentation will discuss how the Design-Build delivery method was applied to the GDBRP. Also, from the program manager/construction manager team perspective, Design-Build lessons learned during the construction phase will be summarized.

** Co-presenter; ** Co-author*

2A PRESTRESSED CONCRETE BRIDGES

Recent Advances in Precast/Prestressed Concrete Bridge Girders Design

Richard Brice • *Washington State Department of Transportation*

Precast/Prestressed concrete girder bridge systems continue to evolve. Two recent advancements are deck bulb tee girders with longitudinal UHPC connections and precambered girders. Deck girder systems have several challenges not found with traditional slab-on-girder bridges include top flange fit-up issues, asymmetric girder sections due to transverse top flange thickening that accommodates roadway geometry, and biaxial stresses and deflections. Building an intentional vertical curve (precamber) into girders is an effective technique for accommodating vertical clearance issues. Precamber introduces new design challenges such as the interaction of the prestressing force with the girder geometry and its effect on camber prediction and increased instability during lifting and hauling operations. The Washington State Department of Transportation (WSDOT) has recently updated the PGSuper computer program to accommodate these innovative bridge systems. This presentation will describe these unique design challenges including strategies to mitigate top flange fit-up issues, modifications to camber predictions and stability analysis adjustments and will summarize how PGSuper supports the design of these bridge systems.

10th Avenue Over Indian Creek Bridge Replacement (Caldwell, Idaho)

Sean Murphy • *Jacobs*

A bridge replacement and a pedestrian underpass provide the City of Caldwell with a unique context sensitive design. Jacobs Engineering (formerly CH2M Hill) worked with Local Highway Technical Assistance Council (LHTAC) and the City of Caldwell to replace the existing 10th Avenue Bridge over Indian Creek in downtown Caldwell, Idaho. The project involves roadway reconstruction from approximately Blaine Street to Arthur Street. The existing bridge was constructed circa 1937 and is a single-span structure composed of the steel bases of railroad box cars without the axles with a concrete and asphalt cover. The project included developing means for pedestrians to traverse below 10th Avenue and context sensitive elements to tie the bridge into the local area, as well as considering bridge type and constricted right-of-way considerations, access issues, Historic Structure and Section 106 and 4(f) constraints, public involvement, stakeholder coordination, and aesthetic enhancements. Administered by LHTAC, the project follows Idaho Transportation Department (ITD) process and plan standards.

The City of Caldwell expressed an interest in a bridge replacement on 10th Avenue that also serves as a gateway into the revitalized downtown area. Jacobs had previously developed improvements along nearby stretches of Indian Creek for the City of Caldwell and had recent hydraulic models of the creek.

We developed a single span bridge replacement utilizing concrete voided slab beams with a composite topping founded on pile supported abutments and a pedestrian underpass composed of a pile supported, cast-in-place culvert. Originally, we intended to keep the existing bridge open during construction but concerns about the performance of the existing bridge led to closing the site for the duration and the use of a short detour.

Besides the unique pedestrian underpass, the site also includes overlooks at the wingwalls, customized railings on the bridge, and steel tube arches mounted on those railings. The project was recently bid for construction where Jacobs will be providing services during construction to the City. LHTAC continues to administer the Federal aid during the construction.

The presentation will focus on the preliminary design, development of the context sensitive elements, environmental clearance with the state historic preservation office, final design of the bridge elements and construction plan development, and the status of the ongoing construction. Additionally, the unique role of LHTAC in administering local Federal aid projects in Idaho will be presented.

Under the Neon Lights: Project Neon HOV Flyover

Nicholas Eggen • *HDR Engineering*

Checking in as the largest and most expensive public works project ever in the state of Nevada, Project Neon is nearly complete in widening and reconstructing 3.7 miles of Interstate 15 in the heart of Las Vegas. Design was completed in March of 2017. This 600 million dollar design-build project will widen and reconstruct three interchanges, build 29 new bridges, and provide new HOV lane access to a highly travelled I-15 corridor.

The bridge designs capitalized on conventional design elements which were utilized, optimized and combined in a way that leveraged individual efficiencies to produce an efficient bridge system design. These included the use of high strength concrete in precast wide flange girders, partial depth precast prestressed deck panels, high yield strength grade 75 reinforcement, large diameter drilled shafts, and post-tensioned substructure elements. All of these were implemented throughout the project and most notably were economically applied to Project Neon's signature bridge — the HOV Flyover structure.

Coming in at 18 spans ranging from 125′ to 162′ in length for a total of 2,600′, the HOV Flyover structure connects the brand new HOV lanes between US-95 and I-15 in a horizontal curve greater than 90 degrees on an 875′ radius. Five high strength California wide-flange precast chorded girders spaced at 13′-7½″ with 4″ partial depth precast deck panels make up the 62′-0″ wide superstructure. The bridge is supported on a combination of single-column hammerhead piers and post-tensioned straddle bents. Single drilled shaft foundations range from 9½′ to 11½′ in diameter, with shaft depths in excess of 100′.

** Co-presenter; ** Co-author*

The design elements used for Project Neon are not new to bridge engineering. However, designers recognized that optimizing individual bridge elements could have a compounding effect leading to an overall more efficient system. This presentation sheds light on the ability to maximize efficiency on standard "everyday" bridge elements.

2B HYDRAULICS, SCOUR AND ANIMAL PASSAGE

Hydraulic and Scour Analyses for a Mission Critical Bridge

Weixia Jin • *Moffat and Nichol*

The 13th Street Bridge crosses the Santa Ynez River at Vandenberg Air Force Base (Base). This "Mission Critical" bridge is vital for the Base's space launch operations. Although the existing 500-foot-long bridge was only 48 years old, it had experienced scour and undermining of the piers after each major flood dating back to 1970, its year of construction. The Base made several attempts to correct the scour problems. However, the counter-measures clogged the channel and were ineffective, and the choked opening resulted in channel incision downstream, making the bridge vulnerable to failure during the next major flood. Further, due to the potential for up to 60 feet of liquefaction, the bridge was also vulnerable to collapse in an earthquake. The solution was to design a new robust bridge to better withstand floods and earthquakes. The new bridge was successfully completed and opened to traffic in 2018.

The team designed the new bridge to properly address the scour and seismic issues, as well as to support heavy transporter vehicles that move space launch cargo across the river. The design conforms to AASHTO LRFD Bridge Design Specifications, including the California amendments, and Caltrans hydraulic design criteria. The main channel of the Santa Ynez River is more than 1,000 feet wide, and the floodplain is nearly two miles wide. The 100-year flow is more than 140,000 cubic feet per second. To construct the replacement bridge within the project's budget, the team optimized the bridge length and designed the roadway approaches to be overtopped. The hydraulic engineering was a critical part of this project.

As part of the bridge design, the team performed hydrology analyses, developed hydrographs for various return periods of floods, performed 1D HEC-RAS and 2D TUFLOW-FV hydraulic modeling. Annual discharges were available from 1907 through 2011. However, the homogeneity of the records was affected by the upstream Bradbury Dam construction in 1953.

The presentation will provide an overview of the project and a discussion of the hydraulic issues and solutions. Discussion points include how the design team developed a homogeneous record of peak annual discharge, accounting for the effects of the Bradbury Dam, analyzed the overtopping of roadway approaches, compared the 1D hydraulic modeling results to the 2D results, and calculated the total scour depth. The design of the scour protection for the bridge abutments and roadway approaches will be described.

Real-Time Pier Scour Monitoring of Arctic Bridges

Mark McBroom • *Michael Baker International*
Garrett Yager • *Michael Baker International***
Gerald Price • *ETI Instrument Systems Inc.***

Vehicle and pipeline bridges spanning major distributary channels in the Colville River Delta on the north slope of Alaska have been instrumented with real-time pier scour systems. During the annual spring breakup flood event, bridge piers are exposed to peak flow conditions and are susceptible to scour. Continuous, real-time monitoring is used to detect maximum scour depths to ensure safe bridge and pipeline operations during peak annual flooding. Ice cover and ice jams pose challenges in acquiring scour measurements and can exacerbate pier scour by intensifying velocities close to the streambed. Single-beam sonars were chosen as a practical solution and mounted on bridge piers most susceptible to scour. The mount design facilitates annual instrument installation and demobilization from the bridge decks and is sufficiently robust to endure ice impacts. After three years in operation, the system has successfully measured streambed elevations below ice cover and during periods of heavy ice floes.

I-90 Animal Overpass Structure

Michael Carfango • *Contech Engineered Solutions LLC*

As part of a 15-mile project to reduce congestion and improve safety along I-90 from Hyak to the Easton vicinity, Washington Department of Transportation (WSDOT) built the first wildlife overpass in the corridor near Price Creek. The animal crossing restores critical habitat connectivity between the north and south Cascades for high mobility species of wildlife such as elk, deer, bear and wolves. A coalition of conservationists and government agencies worked for over a decade to make building the animal crossing a reality. After consulting with the designers of pioneering animal crossing structures in Banff and Montana, WSDOT engineers finalized the concept for the animal crossing structure, and contracted with Contech Engineered Solutions LLC to provide the structural design for the twin-cell precast buried bridge structure that would allow larger animals to pass over I-90 without evening know they were crossing over an interstate highway. The structure consists of one cell of a 72′-0″ span twin-leaf precast BEBO arch for westbound I-90 and a second cell of a 60′-0″ span twin-leaf BEBO arch for eastbound I-90. WSDOT engineers performed the design of everything with the exception of the precast arch units and their foundations. The bid drawings detailed geosynthetic portal walls with a cast-in-place concrete facia with architectural treatments including formliner and staining. The portal walls included an eight foot tall animal exclusion wall to keep wildlife on the structure.

** Co-presenter; ** Co-author*

The successful low bidder chose to value engineer the headwall and wingwall system to a precast panel system. The cast-in-place pedestal wall foundations for the arches also have the architectural formliner and stain finish. The structure is substantially complete with landscaping on top of the structure to be completed in the spring of 2019. Wildlife cameras already show that the structure is being used as a coyote was the first animal captured by the cameras crossing over the structure. This presentation will discuss the considerations that went into the siting and selection of the animal crossing structure itself, design considerations of the twin-leaf twin cell arch structure as well as the constructability and lessons learned during the process.

2C BRIDGE REHABILITATION AND LOAD RATING

Rehabilitation of the Historic Rockville Truss

Brian Byrne • *Lochner*
Guy Evans • *Lochner**

The Rockville Bridge, constructed in 1924 by the National Park Service, is believed to be the only remaining vehicular Parker Through Truss Bridge in the State of Utah and the structure is listed in the National Historic Register and a defining feature of the town. The 220 foot long bridge carries Bridge Road over the Virgin River in the town of Rockville, close to the entrance of Zion National Park, and is the only good crossing for several residences and ranches south of the river. The bridge is posted for 14 Tons, too low for emergency and trash removal vehicles, and so this project has been commissioned by the Town of Rockville to upgrade the bridge to meet a 25 Ton rating. This bridge is a defining and an adored element of the town, and the story of its citizens to save and upgrade this bridge, rather than replace it, is compelling.

In order to increase capacity sufficiently, a timber glulam deck will be used and four of the diagonals will be replaced in kind. Additionally, steel stringers will be swapped out and the floor beams will be strengthened. In this manner, the historic appearance is not only maintained, but enhanced with the timber deck, while upgrading the structure to meet the current needs of the citizens.

The presentation will focus initially on the load rating and decision making process on how to increase the capacity of the existing historic truss while working within a small town budget. The load rating was performed without existing plans and required extensive field measurements and assumptions to be developed. The existing railing system, essentially a hand rail, was left in place and a supplemental timber curb was installed to better protect the truss on this low speed crossing.

The deck stringers were the structural elements that controlled the load rating and so were replaced, and the existing floor beams strengthened with bolt-on plates. Modifications were made to one abutment to allow the bridge to expand and contractor properly for thermal cycles and expansion bearings were replaced once the deck was removed.

The presentation will expand into lessons learned from the construction phase, with adjustments that the contractor has proposed, including swapping out the temporary culvert crossing to a temporary bridge. Lochner provided both the design services and construction inspection, and presenters will include representation from both design and construction phases. Construction will be completed in the winter of 2019.

NSM Titanium Alloy Bar Shear Strengthening of PT Box Girder Bridge

Travis Kinney • *Oregon Department of Transportation*

The McKercher Bridge was constructed in 1957. It represents one of the oldest post-tensioned box girder bridges in Oregon. The bridge is a three cell 4′ deep box girder with 25′-0″ cantilever end spans and a 124′-0″ main span. The structure was load rated following LRFR procedures and was found to have significant shear deficiencies in the main span. The main span shear reinforcement consists of #3 grade 40 rebar at 12″ and 24″ spacing's. Higher levels of analysis were unsuccessful in improving the load rating. Therefore, a strengthening project was required to avoid a significant load posting.

A typical repair detail for shear strengthening is epoxy bonded shear dowels. However, conflicts with post-tensioning ducts in the box girder stems prohibited this solution. Using NSM FRP strips was also considered, but the existing shear capacity was too low for it to be a viable option.

With the exclusion of typical repair details, a unique solution was required. ODOT bridge engineers turned to a recently developed guide on NSM Titanium alloy bars. Ti-bars have many advantages over FRP; higher strength, weather insensitive, and mechanical anchorages for shorter development. All of these factors were essential to a successful design on McKercher.

The presentation will include a brief overview of the load rating effort and historical background of the bridge construction. The design process and deviations from the "Guide for Design and Construction of Near-Surface Mounted Titanium Alloy Bars for Strengthening Concrete Structures" will be presented. Finally, lessons learned during construction will be presented.

Simplified Approach to Load Rating of Corrugated Steel Culverts

Vietanh Phung • *Tran Tech Engineering*
Kash Nikzad • *Tran Tech Engineering**

Corrugated steel culverts are widely used in the nation's transportation network. The load rating of this simple structure type is often time consuming and require a commercial program. The load rating of this structure is per NCSPA Design Data Sheet No. 19 Load rating and structural evaluation of in-service, corrugated steel structures (1995). The most difficult part of the load rating procedure is to determine the effects of live load on this type of structure. Some special-purpose programs are available to load rate this structure.

** Co-presenter; ** Co-author*

This paper presents two different approaches to determine the effects of live load on corrugated steel culverts to load rate corrugated steel culvert.

In the first approach, live load distribution through earth fill is computed per AASHTO Standard Spec 6.4.1: when the depth of fill is 2.0 ft or more, concentrated loads shall be considered as uniformly distributed over a square area with sides equal to 1.75 times the depth of fill. When such areas from several concentrations overlap, the total load shall be uniformly distributed over the area defined by the outside limits of the individual areas; the total width of distribution shall not exceed the total width of the supporting slab. When the depth of fill is less than 2.0 feet the wheel load shall be distributed as in design of slabs with concentrated loads.

In the second approach, pressure on the culvert by a concentrated surface live load can be calculated using Boussinesq's equation. The pressure caused by a truck on culvert is the summation of the pressure induced by each axle.

The results from the two approaches are compared to the results from a special-purpose CANDE program. It is found that reasonable live load distributions can be obtained from these simple approaches. These results can then be used to load rate the corrugated steel culvert.

Load rating examples of different kind of corrugated steel culvert with different earth fill depth are presented as a parametric study.

3A BRIDGE RESEARCH TOPICS

Long Term Bridge Performance Program Status Update and the Recently Released Cloud-Based InfoBridge™ Web Portal

Jean Nehme • *FHWA*

No abstract provided.

Shear Strenghtening of Steel Bridge Girders Using Small-Diameter Carbon Fiber Reinforced Polymer (CFRP)

Hamid Kazem • *Kleinfelder*

Corrosion, lack of proper maintenance, and fatigue are major problems in steel bridges. With competition for bridge funding, innovative strengthening techniques are needed to economically retrofit and extend the life of steel structures.

This presentation summarizes the recent findings and application recommendations of a comprehensive program to examine the use of small-diameter Carbon Fiber Reinforced Polymer (CFRP) strands for shear strengthening of steel bridges.

Traditional strengthening techniques including welding or bolting of steel plates to the existing structure can have the drawbacks of increase of gravity load, high construction cost, specialized labor limitations, and can become prone to corrosion and structural fatigue. Therefore, use of FRP strengthening systems has advantages that can make it an excellent alternative application when conventional techniques fail. The advantages are its high strength-to-weight ratios (ultimate stresses up to 340 ksi), corrosion resistance, and ease of construction in comparison to the use of steel strengthening materials.

The small-diameter CFRP strands are stitched together with a gap allowing each strand to be completely covered by the adhesive material and provide a solid bond to the steel. The program first examined the proposed strengthening system to increase the buckling capacity of steel plates. It then continued to examine the same strengthening system for increasing the shear capacity of steel plates. This implementation was extended to testing large scale beams using the same strengthening system to verify the performance. The effectiveness of the strengthening system was investigated with varying CFRP orientations and reinforcement ratios.

Research findings indicated that the proposed system is effective for shear strengthening of steel bridges and the material used eliminated the debonding failure typical of previous CFRP laminate applications. Based on the research finding, design guidelines are recommended for the field application.

Use of High Early Strength Concrete Class 50AF with Polypropylene Fibers as a Cost-Effective Alternative for Connecting Precast Bridge Girders in the Field

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Leonard Ruminski • *Idaho Transportation Department**
Mustafa Mashal • *Idaho State University***

Accelerated Bridge Construction (ABC) technologies are being adopted by state departments of transportation. Compared to the conventional methods, when ABC is implemented, bridge construction time is typically reduced by 30-70%. This in turn increases public's and worker's safety by lowering exposure to construction activities and also increases mobility and economic opportunities by reducing traffic interruptions and delays. ABC requires that bridge precast concrete components be effectively connected to one another in the field. Currently there is a trend of using Ultra-High Performance Concrete (UHPC) to connect precast bridge deck panels or girders in 6-in. wide closure pours between the precast elements. As an alternative, Idaho Transportation Department (ITD) is proposing to place High-Early Strength (HES) concrete with polypropylene fibers in 10-in. closure pours between girders. The advantages of this alternate material are the reduction in costs and construction time.

In the first phase of this project, an experimental and numerical research project was carried out at Idaho State University to determine the effectiveness of the alternate material and the connection detail. The experimental work consisted of small specimen testing and larger specimens with headed bars. Among the six closure pour concrete mixes considered, one was selected that had the largest compressive and tensile strength values and the lowest shrinkage value. Using the results of the larger specimens, a finite element model of the new connection was developed.

** Co-presenter; ** Co-author*

The behavior of the ITD's 10-in. closure pour connection with the optimum mix longitudinally placed between precast girders of a bridge was studied. For this analysis, the AASHTO's requirements for Strength I, Service I, and Fatigue I Limit States were considered.

The second phase of the project involved field performance of a material similar to the optimum mix selected in the first phase. The HES with fibers was used in closure pour connections between Deck Bulb-T girders of a new two-span bridge in Preston, Idaho. The closure pours in a transverse section of this bridge and other selected girder locations were instrumented with 94 sensors to monitor the strains under small and large Under the Bridge Inspection Trucks (UBITs) as well as larger commercial trucks travelling over the bridge. The closure pour strain gages were placed on the lower headed bars as well as below the deck on the precast concrete and closure pour concrete. At the time of writing this abstract, data under the small UBIT and some of the normal truck traffic data have been collected. The remaining truck traffic data as well as the data under large UBIT will be collected by the time of the Western Bridge Engineers Seminar.

This presentation will summarize the results of the laboratory work, the computer modeling, and the field performance of the alternate closure pour material used in this project.

3B STEEL BRIDGE DESIGN

Cross Frame Design for Curved and Skewed Bridges Using AASHTO LRFD 8th Edition

Travis Butz • *Burgess and Niple*
Jeff Hunter • *Burgess and Niple**

Recent changes to the AASHTO LRFD Bridge Design Specifications have had a significant impact on the design of cross frames in steel girder bridges. The assigned fatigue category for fillet welded connections has increased from E to E', greatly reducing the allowable stress range in welded cross frame members. Load factors applied to fatigue loads have also increased, further reducing effective stress limits. As a result of these changes, designers using traditional analysis and detailing methods often find that required member and connection sizes are much larger than those commonly used in the past. This is primarily a problem in curved and skewed framing arrangements, where large forces develop in cross frame members due to differential deflections occurring between adjacent girder lines.

Publications from the AASHTO/NSBA Steel Bridge Collaboration provide recommendations for the analysis and detailing of steel bridges, including specific provisions for the placement and design of cross frames. When properly applied, these recommendations can reduce cross frame member forces, and help to minimize the size of members and connections. This presentation will review the AASHTO/NSBA recommendations, and discuss their application in practical design situations. Specific items of discussion will include arrangement of cross frames (including staggered and skewed alignments), cross frame configuration (X-type vs. K-type), cross frame member type (angles vs. t-sections), connection type (welded vs. bolted), and analysis methods. The discussion of analysis methods will include an overview of the capabilities of commonly used software packages, along with a discussion of finite-element analysis techniques.

The presenter is a member of AASHTO/NSBA Task Group 13 (Analysis of Steel Bridges) and Task Group 11 (Design) and will discuss existing and forthcoming publications from those groups related to this topic.

8th Street Bridge

Eric Bonn • *OBEC Consulting Engineers, a DOWL LLC Co.*

The 8th Street Bridge over the Umatilla River connects downtown Pendleton, Oregon to largely undeveloped land that has been identified for future City growth. The existing bridge consisted of two steel through truss spans originally constructed in 1909 and was listed on the National Register of Historic Places. The previous structure was deteriorating, was load posted, could carry only a single travel lane, had no provisions for pedestrian or bike traffic, and did not meet Federal Emergency Management Administration (FEMA) requirements for free-board above the 100-year flood elevation.

This project consisted of designing and constructing a replacement bridge and approach roadways to current design standards and located on the same alignment. The designation of 8th Street as an arterial alignment required a roadway section consisting of two travel lanes, two bike lanes, and pedestrian facilities.

A number of financially feasible bridge options were investigated during design. The impacts of some bridge types, including concrete and steel girder bridges, were deemed unacceptable, as the significant increase in grade required would result in extensive property impacts, roadway-and-path-related costs, and would potentially not meet Americans with Disabilities Act (ADA) requirements.

As a result, a steel truss bridge was selected as the preferred main span alternative, providing a vertical alignment similar to the old structure, maintaining the aesthetics of the original structure, meeting the freeboard requirement, and clearing a certified US Army Corps of Engineers (ACOE) levee.

Bridge design challenges included construction scheduling limitations based on annual weather cycles, minimizing right of way (ROW) impacts, Section 408 levee encroachment approval, and Section 106 historic approvals.

General bridge requirements:

- Address bike-ped passage onto and from the trail located on the levee system,
- Design all multi-use paths, ramps, sidewalks, and street crossing to meet ADA standards.

** Co-presenter; ** Co-author*

- Maintain aesthetics complimentary to the community and riverfront community.
- Avoid or minimize impacts to adjacent properties.
- Address and include new water and sewer systems.
- Coordinate structural review and approval by ACOE in regards to meeting FEMA Code of Federal Register 65.10 Provisionally Accredited Levee requirements for freeboard and address current standards for the existing levee prism.
- Address regulatory requirements for in-water work.
- Maintain pedestrian access during construction.
- Effectively communication with affected neighborhoods.

A number of challenges were encountered during construction, including:

- Shallow bedrock under falsework towers
- Fabrication and assembly issues related to the truss
- Misaligned drilled shafts

Three learning objectives of this presentation include:

1. Trusses are viable alternatives given the right combination of design restraints
2. Design of trusses is all in the details
3. Expect fabrication issues

Steel Bridge Member Resistance: AASHTO Compared to Other International Codes

Terry Cakebread • *LUSAS*
Steve Rhodes • *LUSAS***
Bryan Donoghue • *LUSAS***

This paper considers a truss bridge, where member resistance calculations have been performed to AASHTO 7th and 8th editions, Eurocode EN1993-2:2006 and Canadian Bridge Design standard CSA S6-14.

Why are such different utilizations determined from each Code, when using the same loading regime? Why are some members disallowed, in certain Codes, merely on the basis of dimensions? Which Codes are more or less conservative? Which articles from these international codes seem to be most in conflict?

How are the utilizations affected by altering some of the analysis assumptions on which regular bridge designers differ? Which assumptions might affect design safety and efficiency?

The paper explores these questions, giving a full description of the structure in question, assumptions made, and giving detailed references throughout.

3C ABC PROJECTS – MOVERS AND SLIDERS

US-12 Wildcat Creek Rapid Bridge Replacement

Kali Dickerson • *Stantec*
Michael Carfagno • *Contech Engineered Solution LLC**

WSDOT chose to use a fast-tracked DB approach to replace an aging 150-foot five-span timber and steel girder bridge under a tight construction window—seven months after project award. The original Wildcat Creek Bridge, constructed in 1936, was showing significant signs of deterioration due to age and normal wear. Located on US Highway 12, one of three routes across Washington's Cascade Mountains, the bridge was a critical piece of infrastructure for an important freight route.

WSDOT's preliminary design included a standard girder bridge. The agency budgeted $12 million and four to five months of construction. The team developed effective design and construction methods to accelerate the bridge replacement timeline while reducing impacts to the environment, traffic, and the surrounding community. The multi-discipline DB design team conducted an alternatives analysis and developed an innovative solution utilizing a 54-foot pre-cast arch buried bridge structure. Fabricated off-site and trucked in, this solution eliminated the need for custom forms and other cast-in-place elements, including foundations, retaining walls, and traffic barriers—all of which require weeks for concrete to cure on site. With the pre-cast arch units, foundations and retaining wall panels, the curing time occurred at the fabricator's plant, before construction began.

Stantec also eliminated a temporary detour bridge in favor of a full road closure. To determine how long the road would need to be closed, the team built a highly detailed, hour-by-hour schedule that penciled out to 17 days of round-the-clock construction. The team worked with Yakima County and other stakeholders to develop a detour based on a previously used route familiar to the public. By reducing construction to 17 days, the team cut inconvenience to the traveling public, residents, and local businesses by 80% and eliminated the safety concerns and expense of managing live traffic adjacent to the project.

The installation logistics for this remote location, on a tight timeframe, were quite complex. Through careful planning and sequencing, all the parts and pieces were brought together in the correct progression. This included close-coordination with utility owners including AT&T for both temporary and permanent locations of sensitive fiber optic line and Rimrock Water Association (RWA) for potable water and fire suppression lines to confirm that utility relocations occurred on time to keep the project on schedule. The team worked with AT&T to develop conduit locations and collaborated with RWA, assisting with concept development for the use, size, and location of pipe sleeves.

US-12 reopened to traffic on October 22nd, 2018—ahead of schedule. The new bridge restores a safe, reliable route over the Cascades and has received praise from stake-holders and the community alike, who have publicly commended the team for installing the new structure quickly and with minimal impacts while improving aesthetics of the crossing. The new arch structure adds stability, maintains natural hydrology and fish habitat, and compliments local and regional aesthetics. The project has won WSDOT, AGC, and ACEC project awards.

** Co-presenter; ** Co-author*

Accelerated Construction of Unbraced Network Arch Bridge

Mike LaViolette • *HDR*

The 2nd Avenue Bridge represents one of the most unique bridges in the United States—not only due to the skewed, unbraced network arch configuration, but also for the innovative accelerated bridge construction (ABC) process that will be used to construct the bridge during a short closure of I-94.

Interstate 94 carries an estimated 175,000 vpd in a depressed urban freeway configuration. Michigan DOT desires a bridge to span a future widened corridor without the need for intermediate piers that would limit alignment options and result in throwaway construction. Furthermore, the bridge serves the Wayne State University community and provides a signature element of the I-94 corridor reconstruction.

The bridge consists of a 245 ft long, unbraced network arch span, which will carry vehicular traffic, bicycles and pedestrians in separate dedicated lanes, resulting in a 96 ft wide structure. In addition, the arch ribs will be unbraced in the final configuration to create a visually distinctive, community connector structure.

The unique nature of a skewed, unbraced arch structure necessitated considerable analytical investigation of buckling during the SPMT bridge move as well as during final in-service conditions. During preliminary design, the design team worked with a number of steel fabricators and detailers to identify and address potential challenges to arrive at the optimal final design. Due to a number of site constraints which limited construction options, the owner/designer team conducted a series of one-on-one meetings with specialty heavy-lift contractors in order to establish an assumed construction and bridge move sequence prior to the start of final design. This assumed construction sequence was used as the basis for analytical modeling and confirmation of temporary stresses during the bridge move operation.

The selected contractor is currently pursuing a Value Engineering Change Proposal (VECP) that could potentially modify the construction method through the use of precast, post-tensioned concrete tie girders. Details of this change are still being developed at the time of this abstract, but will be resolved prior to the conference and will be discussed as part of the presentation.

This presentation will discuss the bridge design and details, invaluable fabricator and specialty contractor interaction during the design and the final bridge construction sequence that will be utilized. Construction will begin in Spring 2019 and a future presentation could be used to show the full bridge construction process which is currently scheduled for completion in 2020.

Milton Madison Bridge: The Largest Bridge Slide in North America

Michael Killian • *Kleinfelder*
Travis Butz • *Burgess and Niple**

The Milton-Madison Bridge made history when its new steel truss superstructure was moved 55 feet onto its permanent, rehabilitated piers. The 2,428-foot-long main truss span was slid along steel rails and plates into place, making it the longest bridge slide in North America. The bridge, which connects Milton, Kentucky and Madison, Indiana, opened to traffic one week later after final inspections were completed.

The bridge is owned by the Kentucky Transportation Cabinet (KYTC) and is one of only two crossings over the Ohio River between Cincinnati, Ohio and Louisville, Kentucky, which are 100 miles apart. A requirement of the American Recovery and Reinvestment Act funding used to build the project was that the bridge needed to be replaced on its current alignment. The project was implemented as a design-build with provision for a contractor-supplied ferry service to maintain traffic during the bridge replacement. The ferry service, free to users, was to accommodate 240 vehicles per hour during daylight hours for one year. During the bidding process, the successful design-build team proposed an idea to eliminate the ferry service and instead build the new superstructure next to the existing bridge on temporary piers and slide it laterally into place onto refurbished existing piers. This allowed traffic to be maintained on the existing bridge, except for two brief closures. The 2,428-foot-long truss was pulled laterally via sliding harnesses and utilizing its permanent bearings. A 110-foot-long prestressed concrete girder approach span was also pulled laterally using temporary sliding bearings. This innovative approach generated a winning bid of $103.7 million, well below the engineer's estimate of $122 million.

This presentation will provide an overview of the project, a description of the concepts used to maintain traffic, and the processes used for the bridge slide. While the approach span slide was on a much smaller scale than the main span slide, the unique set of challenges encountered will also be discussed.

*Co-presenter; **Co-author

4A BRIDGE INSPECTION AND EVALUATION

M7.0 Anchorage Earthquake: Alaska Department of Transportation Bridge Inspection Response

Jesse Escamilla III • *Alaska Department of Transportation & Public Facilities*

Anchorage is the largest and most densely populated city in Alaska; it was struck with a Magnitude 7.0 earthquake on November 30th, 2018. The Alaska DOT Bridge Section sent four teams of bridge engineers to inspect 262 bridges that may have been affected by the earthquake.

This presentation will focus on the inspection and coordination aspect of the earthquake bridge assessment, giving insight into the logistic seismic response by AkDOT Bridge staff including but not limited to: the selection of bridges to inspect and creating a priority list, recording and generating inspection reports in the field, inspection findings, and coordination with the onsite Emergency Operations Center (EOC). After the fact, bridge design has had the opportunity to reflect upon response efforts and will discuss a list of lessons learned for future emergency response efforts.

Nondestructive Load Testing of Bridges: An Oregon Perspective

Travis Kinney • *Oregon Department of Transportation*

All bridges open to the public are required to be load rated to determine a safe operating limit. Newer bridges tend to rate out well for legal and permit vehicles, but older bridges with poor details can end up with very low recommended operating capacities. It isn't uncommon for bridges in good condition, with over 50 years of unrestricted service, to receive a recommended operating limit of less than 20 tons. Once a load restriction is issued, even bridges in good condition will become a high priority for replacement.

The Oregon Department of Transportation has used nondestructive load testing to refine the load rating analysis, resulting in reasonable safe operating recommendations. Load testing is a valuable tool for Owners to focus their limited replacement funding on the bridges in poor condition.

The presentation will provide a summary and brief overview of two bridges that were load tested by ODOT bridge staff. The bridges were selected to provide a range of load testing goals, methods, results and lessons learned.

BRIDGE OF THE GODS

The Oregon approach spans consist of two built-up plate girders with a cast-in-place concrete deck. Shear studs were not provided to ensure composite action between the deck and the girders at ultimate load levels. The analytical load rating assumed a non-composite section, and recommended a significant load restriction due to insufficient flexural capacity at mid-span. In 2013, the approach spans were proof loaded to verify composite action at service levels, and to assign a safe operating capacity. The target test loading was achieved. Composite action was verified for service levels and the bridge was returned to its previous operating condition.

POWDER RIVER, HWY 66 (BRIDGE ST)

The Powder River Bridge is a 52′-6″ long single span bridge on rolled steel I girders with a composite deck. The analytical load rating indicated insufficient flexural capacity for short haul and annual permit vehicles. 28 girder lines spaced at 2′ on center support the 56′ wide concrete deck. In 2014 ODOT bridge section staff performed a diagnostic load test. Load testing revealed that the live load sharing of the girders was substantially higher than predicted in the analytical load rating. Based on the information gained during the load test, the structure was returned to unrestricted service.

OCHOCO CREEK

The Ochoco Creek Bridge is a 35′-0″ simple span reinforced concrete deck girder. The original plans for the structure were lost. Due to the poor bridge condition a restriction was recommended based on engineering judgment. The reinforcing details of the bridge were determined through GPR and localized destructive investigation. Unfortunately, the reinforcing details were poor, and the analytical load rating recommended a restriction of 13 tons. In 2014, the bridge was instrumented and load tested with two goals: quickly determine a safe operating level (proof load), and collect enough information to perform a load rating calibration. The proof load test was successful in quickly assigning a safe operating load, but the load rating calibration was not able to fully explain the measured bridge responses. Therefore, the full benefit of the load rating calibration was not achieved and a minor strengthening project was required to return the bridge to unrestricted service.

Resistograph Inspection and Repair Methods for Timber Bridges

Amanda Blankenship • *David Evans and Associates, Inc.*
Laura Baughman • *David Evans and Associates, Inc.**

Inspection and repair of existing timber bridges is critical to maintaining this ageing and significant part of the current transportation system. This presentation will show how a resistograph works in the field to provide valuable information about a timber bridge's condition and structural capacity. The presentation includes a live demonstration of the resistograph on a timber bridge element. The presentation will explain how to best use the resistograph results to determine a timber bridge's condition and structural capacity for load rating, load posting, and rehabilitation options. Finally, timber rehabilitation alternatives will be presented including installing helper members, member replacement, and steel splices.

** Co-presenter; ** Co-author*

4B BRIDGE SEISMIC DESIGN

Seismic Analysis and Design of Earth Retaining Systems

Gary Wang • *California Department of Transportation (Caltrans)*
Amir Malek • *California Department of Transportation (Caltrans)***
Susan Hida • *California Department of Transportation (Caltrans)***

Seismic design of Earth Retaining Systems (ERS) has been the topic of number of research projects in recent years. Appendix A11 of the AASHTO LRFD Bridge Design Specification (AASHTO A11) has been developed based on NCHRP Report 611 and together with additional information from Section 3 that covers seismic design of ERS. The AASHTO A11 references conventional methods such as Mononobe-Okabe (M-O) with its limitations, used for estimation of the seismic active soil pressure, as well as Generalized Limit Equilibrium (GLE) method. The Appendix also provides methods to estimate permanent seismic movements of the ERS. Considering variety of the ERS types (gravity/semi-gravity walls, cantilevered walls, anchored walls, MSE, and soil nail walls), each type of ERS needs additional supporting design guidance to show detailed implementation of the AASHTO A11 to avoid adverse impact on cost of wall while preserving the level of desired functionality.

This presentation will concentrate on complementary information that will facilitate implementation of the AASHTO A11 for structure designers. The presentation will start with a brief review of the AASHTO A11 approach for seismic analysis and design of the ERS. Subsequently, proposed classification of the walls based on criticality (importance) and analytical complexity, applicable to AASHTO practice for safety and functionality, will be discussed. The method of estimation of movements for each classification of the wall and associated reduction in the horizontal seismic acceleration coefficient will follow. Seismic design of retaining walls supported on pile foundation will be presented.

Probabilistic Damage Control Assessment (PDCA) Part 1: Introduction, Theoretical Background & Procedures

Mark Mahan • *California Department of Transportation (Caltrans)*
Amir Malek • *California Department of Transportation (Caltrans)***

Seismic design methodology for highway bridges is in transition from a deterministic to a probabilistic based approach to comply with the performance-based earthquake engineering (PBEE) principles. California Department of Transportation (Caltrans) has recently made efforts to implement the PBEE into the bridge design practice. The outcome has been named "Probabilistic Damage Control Assessment" (PDCA).

PDCA is a reliability-based analysis method to identify the probable distribution of modern bridge response to various seismic events. The goal of the PDCA is to quantify the column damage in terms of the probability of exceeding a target performance when the bridge is subjected to any possible earthquake.

This presentation covers the current status of implementation of the PDCA to Caltrans' bridges, followed by the fundamentals of reliability analysis and definitions of engineering demand parameters (EDPs) used in PDCA.

The results of the PDCA study, by Caltrans Structure Policy & Innovation (SP&I), of conducting more than 4,000 NTHAs with the motions scaled using three different methods at ten bridge locations is presented. This study was to confirm the distribution of the statistical parameters associated with various site characteristics and scaling methods.

The presentation concludes with benefits of using the PDCA. The key benefit of using the PDCA is that it helps owners to acquire safe bridges with two primary decision-making parameters: Performance and Cost. The owners can choose a damage state associated with their target performance level and the bridge designer can fine tune the design for the target damage state accordingly. PDCA answers the owner's cost-related questions, whether the proposed bridge is the most economical structure over its lifespan. The designers can conduct a total lifecycle cost analysis using PDCA.

Probabilistic Damage Control Assessment (PDCA) Part 2: Example Applications to Caltrans Bridge Seismic Design

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

As a complement to the presentation "Probabilistic Damage Control Assessment (PDCA) - Part 1" (page 10), detailed application of the PDCA method at two bridge locations in California is presented. The concept of total probability theory is implemented to estimate the probability of exceeding a damage state within the bridge life span, given all possible earthquakes. In Part 1 of the PDCA presentation, only three earthquakes with specific return periods were considered.

The case studies present two different bridges that is a two-span ordinary standard bridge and a seven-span bridge. Each example is formatted using the four distinct stages of Performance Based Earthquake Engineering: Hazard Analysis, Structural Analysis, Damage Analysis, and Loss Analysis.

The first step, hazard analysis, will explain the generation and selection of ground motion acceleration time histories. 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, abutments, and shear keys).

The third step, damage analysis, will explain the estimation of the probability of exceeding a damage state within the bridge life span.

The last step is the loss analysis. This step shows total life cycle cost analysis. At the end of the presentation, probability of failure for a standard bridge and recovery bridge is calculated and compared.

** Co-presenter; ** Co-author*

4C BRIDGE DESIGN AND CONSTRUCTION

Design Considerations for the Manning Crevice Bridge Replacement

Kenneth (Ken) C. Saindon • *Neel-Schaffer, Inc.*
Alex Whitney • *HDR**
Benn Oltmann • *FHWA-WFLHD**
Jesse Webb • *Idaho Transportation Department***

The Manning Crevice Bridge carries Salmon River road across the Salmon River in a picturesque, V-shaped canyon 14 miles upstream from Riggins, Idaho. Salmon River Road provides access to residences, resorts, commercial rafting ventures, and is a main artery for recreational users of the river and forest lands. The site is remarkable due to limited access and very limited space available to stage bridge construction equipment and materials. The existing bridge, built in 1938, had reached the end of its service life and required replacement. The new single tower, asymmetric, earth-anchored suspension bridge has a span length of 300′. The bridge was built on an adjacent alignment to allow the existing bridge to carry traffic while the new bridge was under construction.

This presentation will address the geometric and structural design aspects of the project. Interplay between the roadway geometry and the final structural system will be discussed, including the hanger variations required to accommodate the asymmetric cable profile and the flaring deck edges. From initial concept to final construction plans, many refinements were made to the anchorages, superstructure, and cable system to enhance constructability and lower project cost. Studies to prove the non-fracture-critical nature of the structure will be discussed. Considerations for cable corrosion protection will be presented. Wind tunnel testing for the aerodynamically-blunt superstructure will be touched upon, as will the structural modeling methodology. A brief discussion of the geotechnical considerations for slope stability and suspension bridge anchorage design will be included. Finally, project aesthetics will be addressed as part of the overall design effort to provide a bridge befitting its magnificent setting.

Construction Considerations for the Manning Crevice Bridge Replacement

Benn Oltmann • *FHWA-WFLHD*
Jesse Webb • *Idaho Transportation Department**
Kenneth (Ken) C. Saindon • *Neel-Schaffer, Inc.**
Alex Whitney • *HDR***

This presentation, a companion to the design considerations presentation, focuses on how the contractor successfully overcame the numerous site challenges during construction. The Manning Crevice Bridge crosses the Salmon River in a very challenging and inconvenient location. The crossing is well east of Riggins, Idaho and the only year-round access is the Salmon River Road, which is an unpaved narrow roadway. French Creek Road provides access from the west but, via numerous sharp switchback curves, crosses an arduous 3,000 foot pass which is snow-covered and unmaintained in the winter. At the site, the existing bridge only provided a marginal path across the river given its' constricting geometry and paltry load capacity. Additional site challenges included severely steep work zone, lack of convenient lay-down areas, an environmentally sensitive river below, and the requirement to maintain traffic in the work zone during construction.

This presentation focuses on the construction steps and methods used in constructing a complex structure in a constricted steep canyon location. Methods for site access, equipment selection and delivery, crane access and placement, and cast-in-place concrete batch plant location and sizing will be covered. The construction methods employed to address specific construction challenges constructing in hard rock include rock excavation, installing ground anchors, micro-piles, soil nails, abutments, and tower substructure will be described. Superstructure erection including the tower, suspension cable and hanger system and floor system will be thoroughly described including methods for material delivery, tower stability, cable installation methods and attachment to anchorage, geometry control, and erection of the floor system. The placement and use of crane equipment including temporary crane platforms will be covered as well. Additional topics include methods used to maintain traffic across the existing bridge during construction and to both protect the Salmon River from being fouled by construction as well as maintain locally critical jet boat and commercial rafting in the river. Finally, a brief overview of the benefits of the CM/GC delivery method to construction and some lessons learned will be described.

Design and Construction of the Keechelus Lake Avalanche Bridges

Cory Caywood • *Jacobs*

The Keechelus Lake Avalanche Bridges are a part of the "Snowshed to Keechelus Dam Phase 1C Replace Snowshed and Add Lanes" project. The project is located on I-90 just east of Snoqualmie Pass, about 55 miles east of Seattle, Washington. Overall, the project widens I-90 from two to three lanes in each direction and widens the shoulders to improve safety and capacity. Final design of the bridges began in 2012 with construction completed in 2018. This presentation will give an overview of the project and several design considerations then focus on the construction of the bridges.

The original project included replacing the existing 500′ long snowshed over the eastbound lanes with a new 1,100′ long snowshed over the eastbound and westbound lanes to reduce traffic disruptions due to avalanches. The Keechelus Lake Avalanche Bridges were proposed as a Cost Reduction Incentive Proposal (CRIP) by the contractor as an alternative to constructing a new snowshed. The advantages of the CRIP include reduced construction risk to WSDOT as well as reduced maintenance costs that would be required for the snowshed.

** Co-presenter; ** Co-author*

The bridges are two 1,200′ long bridges (one eastbound and one westbound) which span over several avalanche paths. The bridges are sandwiched between steep terrain on one side and Lake Keechelus on the other. Each bridge has seven spans with lengths ranging from 130′ to 170′. The superstructures are WSDOT wide flange precast girders with a cast-in-place deck supported by drilled shaft foundations. Grade beams and permanent ground anchors were used at several piers due to unstable ground conditions.

The bridges were designed for several interesting loading conditions including avalanche impacts on the piers as well as seismic induced landslides. The design also incorporated methods to reduce construction time considering the limited construction season.

There were several challenges during construction including staging to construct the bridges within the limited space between the steep hillside and Keechelus Lake, limited time during construction seasons, construction of drilled shafts in variable soil conditions, as well as construction of permanent ground anchors.

5A ABC & UHPC

Replacement of a Multi-Span Bridge Over the Snake River Applying Accelerated Bridge Construction Methods

Shane Brown • *Parametrix*

This project involved the replacement of a deteriorating 19-span, 615-foot long precast concrete stringer bridge. The bridge spans the environmentally sensitive Snake River in Idaho. Challenges for this project included:

- Minimizing environmental impacts to the Snake River.
- Maintaining traffic flow during construction.
- Replacement of the bridge in a single year.

To meet these challenges the designed incorporated the following solutions:

- The new bridge was constructed on the same horizontal alignment in two stages to maintain one lane of traffic during construction.
- Span lengths were maximized to reduce the number of in-water piers.
- In-water piers consisted of steel pile bents constructed without the use of cofferdams for ABC.
- The superstructure of the bridge utilized prestressed deck bulb tee girders with ultra-high performance concrete (UHPC) keyways for ABC.

This presentation will focus on the design and construction of the superstructure with UHPC keyways, and the pile bent substructure.

OR 22: Sougrass Creek Culvert Replacement (UHPC Joint Fill in Side by Side Deck Bulb Tees)

Robert Tovar • *Oregon Department of Transportation*

This project is to replace a failing 10 foot diameter culvert with a new single span bridge. The replacement bridge had to use staged construction, and built with in the in water work period. The bridge is 125 feet long Deck Bulb Tee girders filled in with UHPC (Ultra High Performance Concrete) joints. ODOT is looking to replace the existing weldment connection with UHPC joints this will be the second bridge using Deck Bulb Tee girders with UHPC joints. By utilizing UHPC's combination of superior properties with precast bridge deck bulb tee girders, the performance is advanced and improved. The benefits include reduced joint size and complexity, improved durability and continuity, with speed of construction. The project is consider a partial ABC (Accelerated Bridge Construction) project and has precast end panels, but the abutments are cast in place concrete. Another innovation of the this project is that instead of using waterproof membrane and asphalt concrete we will use PPC(Premix Polymer Concrete) on top the Deck bulb tees. ODOT has recent waterproof membrane failures, so this will first project use PPC on a new Deck Bulb Tee bridge. By using the technique ODOT will not have worry about asphalt on the bridge or deck being damaged by future asphalt inlays. This innovative joint design and a variable PPC overlay eliminates problems associated with joints in connections of the precast elements and remove issue of sealing the deck from cracks.

Design and Construction of the Tacoma I-5/SR 16 Interchange HOV Connections: Implementing Features to Accelerate Construction

Thomas Wilson • *WSP USA, Inc.*

The WSDOT Tacoma/Pierce County HOV Program encompasses several projects which together complete 70 miles of HOV lanes stretching from Gig Harbor to Everett, Washington. This presentation discusses a critical link in that connection, the third and final stage of the I-5/SR-16 Interchange in Tacoma, Washington and identifies several key bridge design features that helped accelerate construction.

This $121 million HOV structure and roadway design-build project in Tacoma involves realigning I-5 to accommodate HOV lanes, construction of four separate HOV ramp and I-5 mainline structures, and completion of multiple roadway connections at the I-5/SR-16 interchange. The project establishes new HOV lanes between I-5 and SR-16 that will increase safety, improve mobility and reduce congestion by allowing continuous usage of HOV lanes while merging onto I-5 or SR-16. This presentation will describe the various design innovations and construction challenges that were overcome to complete this project.

Maintaining traffic throughout construction on both I-5 and SR16 was a necessity. Keeping traffic moving while providing room to demolish and rebuild the existing I-5 structures involved innovative staged construction including construction of the NB I-5 bridge wide enough to accommodate both NB and SB lanes. This opened the middle of the interchange for earthwork, grading, and roadway ramp and bridge construction.

** Co-presenter; ** Co-author*

Drilled shafts consisting of integral shaft/column connections were used universally at all pier locations and at one abutment to avoid buried utilities. Where possible, abutments were founded on spread footings either directly on glacial till or supported by soil nail walls. Three soil nail walls were constructed for this project ranging up to 40′ in height. One soldier pile wall and multiple cast-in-place approach walls were also constructed.

Rapid construction was key to completing the project on-time. Two of the four bridges used partial depth stay-in-place panels to accelerate deck construction and minimized installation and removal of deck formwork over live traffic. Precast bent caps were an advancement used at several locations for the HOVSW flyover to minimize falsework and formwork adjacent to traffic. Although these pier caps required more precise survey control and coordination of details, along with modifications made during construction, the bent caps were constructed efficiently resulting in acceleration of the construction schedule.

This presentation will provide an overview of the design phase, highlighting several of the accelerated bridge construction techniques implemented to help facilitate the schedule. Construction progress and challenges will also be discussed, along with lessons learned on how these challenges were overcome. In addition, the overall design-build process for this project will be summarized along with observed benefits and potential improvements for future projects.

5B BRIDGE PRESERVATION

"Bridge Apocalypse": Emergency Bridge Strike Support

Jared Levings • *Alaska Department of Transportation & Public Facilities*
Nicholas Murray • *Alaska Department of Transportation & Public Facilities**

The Artillery Road Overcrossing bridge spans over the Glenn Highway in Eagle River, Alaska. The Tudor Road Overcrossing bridge spans over the Seward Highway in Anchorage, Alaska. Theses two-span post-tensioned concrete girder bridges were struck by over-height vehicles within a year of each other. The extent of damage dictated that the girders be immediately removed. Each underlying main highway traffic lanes were closed up to five days during emergency girder removal operations.

The emergency girder removal for both bridges and the girder replacement for the Tudor Road bridge will be examined. Challenges associated with roadway detours, delays, girder removal operations during the winter season, and girder reinstallation will be will be discussed. In addition, attention to the projects' successfulness, lessons learned, and future DOT guidance will be provided.

Development of Seismic Retrofits for RC Bridge Columns Using Titanium Alloy Bars

Christopher Higgins • *Oregon State University*

Many existing bridges were not constructed to modern seismic design standards. As a result, these structures are expected to perform poorly during a large earthquake. Many older bridges in the US and around the world are supported on seismically deficient reinforced concrete (RC) columns. The most common deficiencies in these columns are lap-splices located in the plastic hinge region above the footing, insufficient lap-splice length, and inadequate transverse reinforcement that cannot confine the core concrete. These three features result in nondutile response and can lead to collapse during a large earthquake. To improve the seismic performance of existing RC bridge columns, a novel retrofit method was developed and tested in the laboratory. The retrofit uses titanium alloy bars (TiABs) (Ti-6Al-4V) combined with conventional concrete. TiABs provide well-defined material properties, excellent corrosion resistance, and ease of fabrication. Continuous TiABs spirals were used to provide confinement and supplemental longitudinal TiABs were added to provide a supplemental and alternative load path that is able resist earthquake induced bending in the column. TiABs were installed using conventional construction industry practices to provide an effective and economical retrofit solution. The specimens with TiAB retrofits produced seismic performance that was as good as or even better than modern seismic designs. The TiAB retrofit solution also allows visual inspection of the column after an earthquake to assess damage, a benefit not available from alternatives. The ability to achieve high seismic performance from older existing bridges can provide significant savings by minimizing the need for replacements.

Yesler Way Over 4th Avenue S Brige: Reconstruction and Preservation

Yanqiang (Carl) Gao • *Seattle Department of Transportation*
Lee Andrews • *HDR**
Joyce Lem • *Retired***

Originally built in 1910, the Yesler Way Bridge was one of Seattle's oldest permanent steel roadway and original streetcar bridges. Carrying the Y-intersection of Yesler Way and Terrace Street over a horizontal curve along 4th Avenue, the bridge footprint flares in an unusual fan-shape. Reconstruction of the aging structure required preservation of the historic and iconic features of the bridge, including the built-up steel fascia girders and their cast iron cladding and the pedestrian railings.

The original bridge had three-spans: short spans ranging from 10 to 17-feet over the sidewalks, and a 54-foot main span across the four-lane arterial roadway and bike lane. At the northwest corner of the bridge, vertical clearance was only 14′-3″. Steel columns at the interior piers were located within 18″ of the curb and the bridge was at risk of collapse if a vehicle impacted any of the columns. The project geometry was complex: in addition to the unusual fan-shaped deck, the bridge profile was nearly 10%, while 4th Avenue followed a 4% grade. Located at a congested

** Co-presenter; ** Co-author*

urban site, the bridge was physically tied to historic buildings at three of its five corners, a historic park, stairway and brick driveway at the fourth corner, and a 33-foot tall retaining wall at the fifth.

The solution was constructing a one-span, steel girder superstructure that eliminated the interior structural columns. The bridge geometry was modified to raise the minimum vertical clearance to 16.0 feet. The unreinforced-concrete gravity abutment walls at the east end of the bridge were partially demolished and reconstructed to receive an integral concrete end diaphragm. The toes of the east abutment walls were modified for seismic loading. The west abutment was totally demolished and reconstructed with 60-foot deep drilled shafts to avoid loading the BNSF Railroad tunnel that passes within 17-feet behind them. After refurbishment, the fascia girders were re-installed such that they support their own weight, but not the bridge deck. The pedestrian railings were modified to meet current design standards, while maintaining the appearance of the original railings.

Everyone was aware of the tight site conditions and that interfacing with the existing adjoining structures, maintenance of traffic along 4th Ave, relocating complexed and congested utilities, and modifications of the approach roadways at each end of the bridge would be challenging during construction. Successfully managing and dealing with the unforeseen conditions – buried behind the bridge abutments and below the 4th Avenue roadway, or hidden behind the cast iron cladding—is a testament to the teamwork between the Contractor, City's construction and engineering staff, and the Consultant design team.

5C LIGHT RAIL BRIDGES

High Load Multirotational Bearings for the HART Project in Hawaii

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

High Load Multirotational Bearings (HLMRB) are a key component for any bridge Project. When the design/build team of Shimmick Traylor and Granite Construction and their design engineers Parsons and IBT put together their bid for the Honolulu Authority for Rapid Transit Project they included disk bearings as part of their package. This presentation will focus on the design, manufacture, testing and installation of these devices. The 268 HLMRB required for this project include features such as high horizontal forces, high rotation and uplift restraint which will be highlighted as well. Other relevant light rail projects will also be discussed to further support the use of disk bearings.

CMGC Design and Construction for a New Transit Corridor in San Diego: Genesee Viaduct Spliced Girders

Pooya Haddadi • *WSP USA, Inc.*

CMGC Design and Construction for a New Transit Corridor in San Diego - Genesee Viaduct Spliced Girders

The Mid-Coast Corridor Transit Project (MCCTP) is the largest transit infrastructure project currently under construction in San Diego, California in the southwest corner of the continental United States. The project will provide an 11-mile light rail transit (LRT) link between downtown San Diego and the University Towne Center (UTC) business and education center, including the University of California San Diego (UCSD) campus.

The $2.2B project includes four miles of aerial structures, 12 bridge structures, nine station facilities and five miles of retaining walls. It is being delivered in a partially shared corridor by a single contractor, encompassing two other major projects to double-track freight and passenger rail in the region. The corridor includes complex river crossings, seismic fault crossings, and viaducts over highway and local streets. This presentation will focus on bridge design and construction within the transit corridor and the project delivery through Construction Manager General Contractor (CMGC) approach.

In addition, the presentation will focus on design and construction of Genesee Viaduct, one of the three major viaducts in the MCCTP. The 1.1-mile-long viaduct runs in the median of Genesee Avenue, a six-lane arterial road with dense concentrations of residential, business and institutional land use. It was critical to minimize impacts to the vehicular arterial during construction, including footprint within the median, and maintaining traffic at intersections within the dense urban area.

The Genesee Viaduct will be the first curved spliced precast U girder bridge in California supporting LRT. It consists of 35 spans and carries two tracks of light rail vehicles. It provides support for two elevated side platform stations. The superstructure section is comprised of primarily precast post-tensioned spliced U-girders except for aerial station frames, which are cast-in-place post-tensioned concrete box girders. The substructure is supported on columns with single drilled-shaft foundations. Project features, design challenges and CMGC interaction during design will be discussed in the presentation.

Design and Construction of the Light Rail Transit Overhead Crossing Seismic Fault Zones

Sami Megally • *Kleinfelder*
Keith Gazaway • *Kleinfelder**

The Mid-Coast Corridor Transit Project in San Diego, California, extends 11 miles and includes the Rose Creek Light Rail Transit (LRT) Overhead, a 12-span bridge carrying light rail and crossing over an active heavy railroad. The project includes nine stations and serves major activity centers such as the University of California, San Diego and Westfield University Towne Centre.

The Rose Creek LRT Overhead carries two parallel LRT tracks, with direct fixation to superstructure, north across the creek within the Metropolitan Transit System right-of-way. However, the greater purpose of the bridge is to carry the LRT tracks over the Los

** Co-presenter; ** Co-author*

Angeles–San Diego–San Luis Obispo Rail Corridor Agency (LOSSAN) mainline tracks. The project has several challenges including very tight geometric clearances, maintenance of the heavy rail traffic during construction, and challenging seismic conditions. To gain sufficient horizontal clearances, outrigger bent caps were used at some of the bents. The difference in stiffness between the outrigger and single-column bents caused some challenges in seismic design. Precast prestressed concrete girders were used for construction of the superstructure to minimize disruption to the heavy railroad activity. Use of precast girders caused some geometric challenges as the bridge has a curved horizontal alignment.

The most significant design challenge was the bridge crossing a major seismic fault. Extensive field investigations were performed at the project site, and surface fault rupture displacement estimates were developed for design. The active Rose Canyon Fault Zone crosses the bridge alignment, affecting two spans and their supporting foundations. The estimated fault rupture displacement is approximately five feet in the longitudinal direction of the bridge and about 1.2 feet vertically. The bridge was designed and detailed to accommodate these severe seismic displacements. To overcome these difficulties, a multi-discipline approach between structural and geotechnical engineers was used, and a comprehensive analysis and modeling of structure, soil, and their interaction was developed. Extensive analyses have been performed to ensure integrity of foundations crossed by this major active fault surface. Seismic design criteria is to prevent collapse of the bridge under the maximum credible earthquake/fault rupture. In addition, an operational level earthquake was determined and used for design to ensure the bridge remains fully functional under lower level earthquakes.

Construction of the bridge is currently underway and would be nearly complete by the end of 2019. Construction challenges include maintenance of the railroad's activity, cambers due to the use of relatively shallow precast girders, and construction loads on the outrigger bents. The focus of this paper is to discuss design and construction of the bridge.

6A SEISMIC DESIGN AND RETROFIT

Strong Ground Motions of the 2018 Anchorage Earthquake

Nicholas Murray • *Alaska Department of Transportation & Public Facilities*

A magnitude 7.0 earthquake struck just outside the most populated city in Alaska on November 30, 2018. While there were dramatic images of slope and roadway failures immediately following the event, very little damage was discovered on bridges. In the weeks following the earthquake the data from strong motion sensors in the Anchorage area was analyzed and compared to AASHTO seismic design spectra to explain why minimal bridge damage was observed. Each pair of ground motions recorded by nearby stations was evaluated through various rotational angles (RotDs) to illustrate the potential variations in ground motion with respect to structure orientation. The analysis revealed that the Anchorage earthquake had significant directionality effects. Differences in damage were seen at neighboring bridges with differing orientations. The strong motion data was also evaluated as a screening tool to determine if AK DOT&PF's inspection response was focused in the correct geographical areas and how the Department can better use strong ground motions in the future.

Widening and Phase 2 Seismic Retrofit, Sunnyside Road Over I-205 Design Challenges

Douglas Kirkpatrick • *OBEC Consulting Engineers, a DOWL LLC Co.*
Guy Hakanson • *OBEC Consulting Engineers, a DOWL LLC Co.**
Eric Vavra • *OBEC Consulting Engineers, a DOWL LLC Co.***

OBEC prepared bridge design plans for multi-modal improvements in the Clackamas Regional Center east of downtown Portland, OR. The project will improve the safety of pedestrian and bicycle facilities and increase traffic flow through the commercial center with additional lanes on SE Sunnyside Road. As the region is divided by I-205, widening of the existing 320-foot-long, two-span bridge over the major interstate is critical to the project's success. The existing bridge is a cast-in-place, post-tensioned (PT) box girder, and will be widened in-kind to provide similar aesthetic and seismic behavior. There were two unique challenges of the design. The first was that the existing bridge reinforcement detailing is insufficient for the 1,000-year return seismic event.

The second was maintaining minimum vertical clearance during construction when the girder soffit finish grade is expected to be at the minimum clearance height.

A seismic capacity assessment per the FHWA Seismic Retrofitting Manual and ODOT's Bridge Design Manual showed the existing column and spread footing as deficient for the "Life Safety" 1,000-year return event in the bridge's widened configuration. Seismic retrofit work includes thickening and anchoring the spread footing, and strengthening the pier wall with shear anchors and carbon fiber-reinforced polymer (CFRP) sheets.

Due to limited vertical clearance over I-205, constructing the widened bridge at finish grade is not feasible due to required falsework. To address the associated design and constructability challenges, two unique construction sequence alternatives were considered. The first assumed the entire widened PT box girder will be constructed multiple feet above its final position and lowered to its finish grade elevation on the column after post-tensioning. The second alternative assumed the outside two-thirds of each span is constructed, lowered, and subsequently connected to the remaining two-thirds at the interior column with full-depth closure pours and additional post-tensioning in the bottom slab. Ultimately, the former alternative was chosen as having the least complicated staging and design.

** Co-presenter; ** Co-author*

To facilitate the required construction sequence where the box girder is separated from the column during construction, non-typical connection detailing was necessary. Following NCHRP's 2017 Recommended AASHTO Guide Specifications for ABC Design and Construction, a grouted duct connection between the interior bent column and box girder crossbeam was utilized.

Construction of this project is anticipated to begin in Fall 2019.

The presentation will focus on three areas:

1. Phase 2 seismic analysis of the widened bridge, including existing columns and footings.
2. Evaluation of alternatives for widening and lowering the PT Box into its final position.
3. Design and detailing of the final bridge widening and retrofit configuration, including grouted duct connections and CFRP strengthening.

Seismic Retrofit of the Approach Bridges to the I-90 Floating Bridge Over Lake Washington

Yakov Polyakov • *WSP USA, Inc.*
Matthew Barber • *WSP USA, Inc.**

This project is a part of Sound Transit East Link Extension under which a number of highway bridges along I-90 corridor between Seattle and Bellevue were converted for Link Light Rail service. The structures were strengthened for increased vertical loads and retrofitted to meet current seismic requirements. The project currently is under construction.

This presentation will concentrate on the seismic evaluation and retrofit design of East and West approaches to the floating bridge over Lake Washington and feature a description of the current state of construction.

The retrofitted structures used to carry HOV lanes and are separate from the bridges carrying main lanes of I-90. Each approach (approximately 1,500 feet long) comprises seven-span continuous segmental concrete box-girder and steel transition span between last fixed pier and pontoon of the floating bridge. The in-water piers are based on elevated pile caps comprising battered four-foot diameter steel pipe piles.

Due to highly nonlinear behavior of such foundations, the structure was assessed by means of nonlinear time-history analysis using ADINA FE software. The modeling captured nonlinear effects of materials, geometry and of soil/structure interaction.

The analysis outcome revealed that stiff, land based piers attract majority of longitudinal seismic force and therefore, are very vulnerable. The retrofit solution was developed to reduce forces on these piers by including land piers with the guided bearings into longitudinal earthquake resistance system. The viscous damping devices (VDD) were to transfer seismic force from the superstructure to the guided piers.

Variety of other seismic retrofits were further designed to enhance seismic performance such as foundation strengthening with ground anchors and micropiles, pile cap strengthening, superstructure transverse restrainers and column jackets.

The retrofit work required a high degree of contractor coordination and field verification including the locating of embedded existing post tensioning and mild steel reinforcing via x-ray and ground penetrating radar.

6B ABC PROJECTS

ABC Techniques on the Garnet Interchange Project

Jared Olsen • *Horrocks Engineers*

The Design-Build team of Ames Construction and Horrocks Engineers was selected by the Nevada Department of Transportation to redesign and reconstruct the I-15 Garnet Interchange and provide improvements to the US-93 corridor in Clark County, Nevada. The Design-Build team opted to utilize Accelerated Bridge Construction (ABC) techniques to meet the goals of the project through the Alternative Technical Concept (ATC) process. ABC elements at two different bridges including full depth precast concrete deck panels and precast/prestressed voided slabs were selected by the Design-Builder as the Best-Value approach.

The project included: reconstruction of the I-15 on and off-ramps to provide adequate acceleration, deceleration, and storage length for turning and merging traffic; replacement of the existing I-15 bridges to provide adequate span length to accommodate crossing roadways and adequate width for future widening of I-15 to three lanes in each direction; US-93 and frontage road intersection modifications to provide access and satisfactory traffic operation in conjunction with the adjacent Garnet Interchange; US-93 widening from two lanes to four lanes, with future widening to six lanes from MP 52 (Garnet Interchange) to approximately MP 57 (five to six miles to the northwest), including widening of shoulders and pavement rehabilitation of the existing pavement; US-93 intersections improvements at US-93/Apex Great Basin Way and US-93/Apex Power Parkway to accommodate future economic growth in the area; US-93/Grand Valley Parkway access improvements at the US 93/Grand Valley Parkway intersection to accommodate high-volume turning traffic including a grade separated interchange bridge for southbound US 93; and a frontage road to provide a minimum of two general-purpose travel lanes to provide access to properties adjacent to US 93.

As construction of the new I-15 interchange was the critical path of the project and to reduce traffic impacts to the traveling public, full depth precast deck panels were utilized as an ABC technique resulting in significant schedule savings. Utilizing precast deck panels reduced the number of closures to US-93 below to construct the bridge. Precast deck panels were also used at the approach slabs

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providing a consistent superstructure type the full length of the bridge. Phased bridge construction and demolition were required to maintain two lanes of traffic during the entire duration of the project.

Another ABC technique was utilized at the US-93/Grand Valley Parkway bridge consisting of a precast/prestressed voided slab superstructure, which eliminated the need for deck forming and significantly reduced the structure depth resulting in significant cost and schedule savings to the project.

Lessons learned for the project include: manufacture's recommendations for grout placement and preparation, field tolerances for construction and inspection purposes, tolerances for field adjustment of precast elements during design and post-tensioning duct alignment and protection.

Constructability Based Design for Accelerated Bridge Construction

Gregg Reese • *Modjeski and Masters*

The popularity of Accelerated Bridge Construction has created new opportunities for creative applications of precast concrete as a response to the desire of Owners to realize greater economy and durability while facilitating faster construction means and methods that provide less disruption to existing traffic.

This paper will discuss the use of Constructability Based Design to develop new construction methods using precast concrete in bridge construction for both complex and conventional projects. The objective of this method is to make constructability a primary focus of the design process. This approach produces bridge designs that are elegant in their simplicity resulting in greater ease of construction resulting in decreased construction times, increased economy and improved quality.

The paper will feature several existing bridge projects, both simple and complex, where constructability-based design and precast concrete construction was used successfully to accelerate the project schedules and reduce the impact to existing facilities. The presentation will also feature innovative means and methods used during construction utilizing sophisticated construction engineering designs that simplified erection methods and minimized or eliminated ground-based support during construction. The paper will demonstrate how Constructability Based design can be used to achieve the objectives ABC using precast concrete as the predominate material.

A Precast Pier System for Accelerated Bridge Construction in High Seismicity

Mustafa Mashal • *Idaho State University*
Leonard Ruminski • *Idaho Transportation Department*

Grouted ducts and grouted couplers connections have been used in construction of precast pier systems by several departments of transportation (DOTs), including the Idaho Transportation Department (ITD), in the United States. These types of connections intend to emulate the traditional cast-in-place behavior (e.g. formation of plastic hinges in the column) during an earthquake. Past studies have shown good seismic performance of these connections. However, there are some construction challenges with these types of connections. One of the issues is the difficulty in lining up column rebars during the column/cap erection. Another challenge is the protection of the rebars protruding from the precast columns against damage during transportation and handling. Further, placement of column rebars in the precast yard requires high precision in order to exactly match the grouted ducts or grouted couplers within the cap. The grouting operations on-site may also be challenging due to difficult access high above the ground while the cap beam is suspended in the air. At the same time, the cap often needs to be externally braced until grout hardens within the ducts or grouted couplers. The above listed challenges make precast pier construction sometimes difficult and expensive. Precast caps with the currently used grouted ducts or grouted couplers connections are usually heavy, making them difficult and expensive to transport and handle. This aspect alone is often an obstacle large enough as to preclude accelerated bridge construction (ABC) methods with precast piers, and instead to use much slower conventional construction methods such as cast-in-place. In this research, an alternative simplified connection using steel pipes is proposed for precast pier systems in seismic regions. In this type of connection, a steel pipe is protruding from the concrete column that will go inside another larger pipe placed in the footing/cap beam during the prefabrication. The gap between the pipes is grouted with high strength mortar after the assembly on-site. This connection eliminates the risk of misalignment and provides ample construction tolerance. The cap beam is a precast hollow shell. This helps with reducing the weight during transportation. The cap is later filled with high-early strength concrete on-site. The column-to-footing and column-to-cap connections are detailed such to act as moment connections. In order to verify seismic performance of such a pier system, large-scale experimental testing is carried out on cantilever and bent pier systems in the Structural LAB (SLAB) at Idaho State University. The specimens are tested under quasi-static cyclic loading with increasing drifts. Benchmark cast-in-place specimens are tested to compare the results and seismic performance between the precast and cast-in-place connections. Results from experimental and analytical work thus far are presented.

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6C BRIDGE ASSET MANAGEMENT AND LOAD RATING

Inspection Data in Action

Elizabeth Hunt • *Oregon Department of Transportation*

This presentation will highlight national and Oregon initiatives that use inspection data. Bridge and tunnel inspection data is collected for more reasons than just to meet the federal NBIS and NTIS requirements. Inspection data is being used to evaluate past conditions and project future conditions as part of a national Transportation Asset Management Program. It is also used to identify candidate projects for future STIP work. Recently, new tools have become available that allow data to be readily queried by different user groups—not just bridge folks. Datasets have been prepared for local agencies, ODOT and public viewing in an effort to be more transparent and also to allow structure owners to better understand the conditions of their inventory.

Redundancy Analysis of the St. Johns Suspended Spans

Greg Griffin • *David Evans and Associates*
Tim Link • *David Evans and Associates**

Redundancy can be defined as a structures ability to continue to carry load after failure of one or more of its members. The bridge engineering community has acknowledged for some time the importance of providing alternative load paths within designs. The AASHTO Standard Specifications for Highway Bridges, 17th Edition, encouraged designers “to use continuity and redundancy to provide one or more alternative load paths”. No further guidance for design or detailing was provided. In 1994, AASHTO issued the reliability based LRFD Bridge Design Specifications (LRFD) and provided calibrated load modifiers to account for redundancy. Although this provided some rationale for engineers to account for redundancy in designs, specific guidance was not provided for different bridge types. Further related to LRFD, the AASHTO Manual for Bridge Evaluation (MBE) uses a system factor to modify the capacity in lieu of ductility and redundancy load modifiers to quantify a systems capability to redistribute loads after initial failure. According to the MBE, system factors typically vary from 0.85 to 1.0 but could be as high as 1.2 depending on the structural system. The system factors presented in the MBE were calibrated to a reliability value commensurate with LRFD and specific bridge types using procedures in NCHRP Report 406, Redundancy in Highway Bridge Superstructures (NCHRP).

One complex structure David Evans and Associates (DEA) has been evaluating for the Oregon Department of Transportation (ODOT) is the St. Johns Bridge including the suspended spans. Constructed in 1931, the St. Johns suspension bridge has a main span of 1,207′-0″ with side spans of 430′-3″. The structure has a riveted stiffening truss, discontinuous at the main towers. Based on the stiffening truss type, an appropriate system factor was selected using the MBE as 0.9 without further analysis. A load capacity analysis of the structure revealed the stiffening truss controlled with rating factors less than 1.0. To avoid posting of this important structure and to minimize potentially expensive retrofit costs, a redundancy analysis using the methods outlined in the NCHRP report for the suspended spans only were conducted to show a higher system factor of 1.2 could be justified which could result in truss member capacity increases of 33%. Using a nonlinear computer model in MIDAS Civil to determine load factors at different failure limit states, the analysis indicated a system factor of 1.2 could be used for all members in the stiffening trusses.

This presentation will discuss the following:

- Brief history and discussion of the St. Johns Bridge;
- Overview of basic load rating methodology;
- Discussion of reliability analysis and results, including nonlinear modeling; and,
- Discussion of resulting system factor modifications

Bridge Economy and Life Cycle Costs of Steel and Concrete Bridges

Michael Barker • *University of Wyoming*

State, county and municipality bridge owners are replacing and need to replace many older and deteriorated bridges in their inventories. A common concern they face is selecting economical bridge material, construction techniques and protection systems that will perform well throughout the bridge service life. This presentation examines First Costs and Life Cycle Costs (true agency costs) of typical concrete and steel girder type bridges. First Costs analyses are based on actual bridge projects. For Life Cycle Costs, historical life histories of simple and multi-span, short and medium span length, rolled-shape, plate-girder, precast box, and precast I-beam bridges were collected and analyzed. The bridges considered were built from 1960 forward (the modern era of steel and precast concrete construction) with span lengths up to about 500 ft. The presentation will demonstrate life performance and life cycle costs of over 1,700 typical steel and concrete bridges. The results, comparisons and conclusions will give owners information on expected performance and investment costs of various bridge alternatives as they administer their bridge replacement programs.

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7A RAILINGS, BEARING AND JOINTS

2019 MASH 2-Tube Bridge Rail

Sara Manning • *Alaska Department of Transportation & Public Facilities*
Elmer Marx • *Alaska Department of Transportation & Public Facilities**

The State of Alaska Department of Transportation and Public Facilities and the North Dakota Department of Transportation have teamed up with Texas A&M Transportation Institute to test the new 2019 MASH 2-Tube Bridge Rail. The State of Alaska DOT & PF provided TTI with a proposed design for the 2019 MASH 2-Tube Bridge Rail and Bridge Transition Rail that satisfied the guidelines in the American Association of State Highway and Transportation Officials, Manual for Assessing Safety Hardware. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and according to the MASH guidelines and standards. With the results, Alaska has begun implementation of the new 2-tube bridge rail and transition rail.

This presentation will go into details of the modifications that were made in the design of the 6.5 inch taller 2019 MASH 2-Tube Bridge Rail and Bridge Transition Rail(s). The 2019 MASH 2-Tube Bridge Rail which was previously called the Alaska Multi-State 2-Tube Bridge Rail design was improved to meet the performance requirements of the MASH Test Level 4. There will be crash-testing videos; test success's and test failures, and final results including detailed plans of the new bridge rail. Details on bridge rail transition(s) systems will be discussed and how they were modified to fit the new 2019 MASH 2-Tube Bridge Rail.

Through this process the State of Alaska Department of Transportation and the North Dakota Department of Transportation have learned the processes for upgrading bridge rail design standards to MASH TL-4 and how to implement the 2019 MASH 2-Tube Bridge Rail on new bridge design projects and existing bridge rehabilitation projects and will share this valuable information in the presentation for other states to utilize.

Experiences in the Performance of Bridge Bearings and Expansion Joints Used for Highway Bridges

Bijan Khaleghi • *Washington State Department of Transportation*

This presentation focuses on finding of the Domestic Scan 17-03, Experiences in the Performance of Bridge Bearings and Expansion Joints Used for Highway Bridges. Scan was initiated to facilitate the exchange of recent ideas and best practices for Bridge Bearings and Expansion Joints, and included design, performance evaluation, maintenance and repair/reconstruction. Discussions involved staff from design, construction, maintenance and operations of state and other transportation agencies. Details for various bridge types (i.e. materials, span arrangements, geometry) and sizes were examined. The workshop offers lessons learned from experiences by the various participating agencies and provides guidelines for design and details, construction specifications and maintenance procedures for durable bearings and expansion joints.

The findings of this scan are expected to be of specific interest to the AASHTO Committees on Bridges and Structures, Materials and Pavements, and Maintenance. The scan will provide current information on successful expansion joints and bearings to bridge owners. It will also provide valuable information to the AASHTO Committees for future consideration when developing their work plans and research needs.

Practices vary widely among states for design, construction, maintenance and even terminology for joints and bearings. The differences in practices arise partly from the different climates, and partly from the policies instituted by the different states. Joints and bearings have the potential for incurring ongoing costs, such as for maintenance and replacement, that are significantly higher than the initial costs. Therefore expected life-cycle costs should be considered when selecting them. Eliminating the joints on the bridge itself, by using jointless construction, provides advantages. If joints are included on the bridge, failed joints in themselves constitute a problem, but leakage of failed joints has further consequences, such as damage to bearings, supporting members, and girder ends. For large movements, modular joints are the most common choice in new construction, although finger joints are still used. For medium movements strip seals and pre-formed silicone seals are the most widely used. For small movements (less than 2″) a wide variety of joint systems is commercially available, and no one type dominates the market. Elastomeric bearings are the bearing of choice for short and medium span bridges. They are economical, durable and perform well in practice. Their primary problem is "walking" out of place. For longer spans and higher loads spherical, disc and pot bearings are commonly used. Some states ban pot bearings, largely because of leaking elastomer in some early designs. Disc bearings are gaining an increasing share of the US market, because, compared to pots, they are cheaper and easier to inspect. However, pot bearings are widely used in Europe, and disc bearings are not used at all there.

Simple Approach to Calculate Displacements and Rotations in Integral Abutment Bridges

Suhail Albhaisi • *Stantec*
Mohammed Maqbool • *Stantec**

This paper presents a simple approach to calculate the displacements and the rotations induced by thermal loading in Integral Abutment Bridges (IABs). The approach was derived from the results of a parametric study that investigated the effect of substructure stiffness on the performance of short and medium length steel IABs built on clay and sand under thermal load effects. Various parameters such as pile size and orientation, pile material, and foundation soil stiffness were considered in the study. Detailed three-dimensional (3D) Finite Element (FE) models using the software LUSAS were developed to capture the overall behavior of IABs. The developed 3D FE model was calibrated using field measurements obtained from

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a previous study. Using the calibrated models, a parametric study was carried out to study the effects of the above parameters on the performance of IABs under thermal loading using the American Association of State Highway Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) temperature ranges. The study showed that most of the parameters have significant effects on the displacement and rotation of the abutment and the supporting piles. Also, for relatively wide IABs, there are significant variations in the displacement and rotations in the substructure elements between interior and exterior locations. This approach, which consists of using simple equations and charts and including parameters such as the length of the bridge, the stiffness of the foundation soil, and the pile location provides results that are comparable to those and in lieu of using a detailed FE analysis.

7B LONG SPAN CONCRETE BRIDGES

Designing Precast/Prestressed Concrete Bridge Girders for Lateral Stability

Richard Brice • *Washington State Department of Transportation*

Lateral stability of precast-prestressed concrete bridge girders is a serious concern. The AASHTO Committee on Bridges recently adopted revisions to the LRFD Bridge Design Specifications addressing design of precast-prestressed concrete bridge girders for lateral stability during handling and transportation operations. The ninth edition of the AASHTO LRFD Bridge Design Specifications will implement these new requirements. Bridge design engineers should begin familiarizing themselves with stability design requirements. This presentation will highlight the new LRFD provisions, stability analysis practices recommended by the Precast/Prestressed Concrete Institute (PCI), and describe how the Washington State Department of Transportation (WSDOT) has incorporated these practices into the girder design process.

Long-Span Lightweight Concrete Bridges… and the Parrotts Ferry Bridge

Reid W. Castrodale Ph.D., P.E. • *Expanded Shale, Clay, and Slate Institute*

Lightweight concrete has been used in main spans of the three longest-span concrete box girder bridges in the world, including the Stolma Bridge in Norway with the current world record span of 301 m (988 ft). Lightweight concrete has also been used in long truss spans, such as the Lewis and Clark Bridge over the Columbia River built in 1930, and the upper deck of the suspension spans of the San Francisco-Oakland Bay Bridge built in 1936. Both of these early bridge decks were constructed with 95 pcf concrete, and the Bay Bridge upper deck is still in service today. Lightweight concrete has also been used for long pretensioned concrete girders, including 160 ft long girders for the emergency replacement of the I-5 Bridge over the Skagit River; spliced and post-tensioned precast girders with spans up to 240 ft when combined with a lightweight concrete deck slab; and the longest spliced girder span in the US at 325 ft with a 185 ft long lightweight concrete drop-in segment. In spite of these successful projects, some owners, designers and contractors remain reluctant to use this material for long-span structures.

Part of the reluctance in using lightweight concrete for long-span bridges, especially in the western U.S., may be the experience of the Parrotts Ferry Bridge in California, a lightweight concrete cast-in-place segmental box girder bridge completed in 1979 as one of the first segmental bridges in the U.S. With a main span of 195 m (640 ft) and a depth at midspan of 2.44 m (eight feet), this very slender bridge experienced significant sag at midspan that continued to increase with time. The bridge was eventually retrofit to strengthen the structure, remove some of the sag, and stabilize the movement of the bridge. From this experience, many bridge engineers assumed that lightweight concrete was not suitable for use in such long span structures.

After describing a number of long-span bridge projects of various types that have been successfully constructed over the years using lightweight concrete, information will be presented on the Parrotts Ferry Bridge that will shed light on the causes of the unacceptable performance of this structure. Data on creep and shrinkage of lightweight concrete will also be presented to show that the time-dependent behavior of lightweight concrete is very similar to what is expected from normal weight concrete, so lightweight concrete is a suitable material for use in long-span bridges, including segmental box girder construction.

Design and Construction of the Centennial Bowl Interchange, Las Vegas, NV

Michael Taylor • *Nevada Department of Transportation*

The US-95 Northwest Corridor in Las Vegas is one of the fastest growing areas in Southern Nevada. The US-95/Clark County-215 Interchange serves as a critical link for regional commuters between predominately residential areas in northwest Las Vegas and the large employment centers in downtown Las Vegas. Currently the third busiest intersection in the state of Nevada, the US-95/CC-215 "Centennial Bowl" Interchange Project will upgrade the existing at-grade intersection to a full four-level system-to-system interchange to meet the growth demands in the region.

The Nevada Department of Transportation (NDOT) is leading the design efforts for the Centennial Bowl Interchange. Once complete, the three project phases will have constructed 19 new bridges, ranging from simple span grade separations to 2,600-ft+ long, 70-ft tall flyover structures. NDOT is delivering the Centennial Bowl via the design-bid-build method.

Due to the complexity of the project, the bridge type selection for the Centennial Bowl Interchange needed to find the right balance between economy, geometric constraints, constructability, main-

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tenance of traffic, aesthetics, and long-term durability. During the type selection phase, NDOT selected cast-in-place post-tensioned concrete box girders to meet the needs of the project.

The objective of this presentation is to give an overview of the design and construction of the Centennial Bowl Interchange, but also to offer a look into several other considerations that have contributed to the success of the project. The choice of cast-in-place construction has proved beneficial to the local Nevada economy by keeping bridge related material and labor resources within the state, contrasting with other bridge types that must be fabricated or cast out of state and shipped in. NDOT designed and managed the project with predominately in-house resources, an approach that has challenges and opportunities but ultimately contributed to a successful project.

7C LESSONS LEARNED FROM DESIGN AND CONSTRUCTION

San Mateo Bridges Replacement Project, San Mateo, CA

Benjamin Consolacion • *WSP USA, Inc.*

The main project constraints involved limited space within right of way for construction activities, the proximity of residential properties, and limitations on the durations of track closures for bridge replacements. Through close coordination with Caltrain, the City of San Mateo, adjacent residences, and multiple utility agencies, replacement strategies were identified. Track operational requirements dictated that the structures would be replaced over short weekend closures. In order to accomplish the replacements, accelerated bridge construction (ABC) methods were utilized. The steel bridge superstructures were fabricated off-site and assembled adjacent to the existing structure during street closures. Soldier Pile retaining walls were constructed and tracks were raised by about 4′-6″ to final grades prior to the weekend track closures. Existing bridge demolition and bridge replacement occurred in separate weekends using double track shut down windows of 32 hours each. Precast abutment caps were used to facilitate the abutment rehabilitation. The new bridges were rolled into place with a self-propelled modular transporter.

Through close coordination with the public and all team members and by utilizing ABC methods, the project was able to enhance public safety, improve the corridor, and replace the four grade separation structures on schedule with minimal impact to commuter train operations. The four 100+ year old structures were replaced with new structures designed and constructed according to current standards and are expected to help improve and maintain Caltrain service into the future.

Lightweight Backfill Solutions to Bridge Problems

Jason Hickey • *Mark Thomas*
Tyler Bodnar • *California Nevada Cement Association**

Bridge construction materials are constantly undergoing innovation to meet challenging project needs. Challenges such as tall fill heights, large abutments, poor soil bearing, liquefaction, limited workspace, and tall retaining walls can create constructability issues and drive up project costs. Design engineers and contractors are working together to develop cost-effective solutions to address these challenges. Lightweight backfill solutions such as cellular concrete (LCC) and expanded polystyrene (EPS) blocks can improve constructability within confined locations and serve as excellent tools for a bridge engineers and contractors to utilize on their projects. The use of these materials can reduce construction costs and improve constructability within confined locations.

This presentation will outline the potential situations where lightweight backfill can provide an effective solution. The presentation will review three recent case studies to demonstrate the design considerations, approvals, construction, and maintenance lightweight backfill. LCC was used for the I-80/I-680/State Route 12 Interchange Construction Package 1 to reduce the need for ground improvements and improve constructability. The project required soil improvements within a slope surrounded by retaining walls on all sides. LCC was used to accommodate right of way constraints and to reduce the cost of ground improvements and retaining walls. The Downtown Roseville Pedestrian Bridge Project also benefited from the use of LCC backfill. There were multiple tall retaining walls in a small area behind the bridge abutments with low allowable soil bearing pressure. The lightweight fill allowed the bridge and wall footings size to be reduced and improved constructability. The Southern Heights Bridge Replacement Project is located on a steep side slope and in very close proximity to existing residences. Utilizing EPS blocks for the backfill behind the abutments allowed for the bridge to be shortened because of the reduction in loads on the abutments and foundations. This dramatically improved constructability of the project and helped reduce the burden of a constrained site.

The presentation will also discuss the ongoing process to include these materials in the California Department of Transportation (Caltrans) pre-approved materials list. California Nevada Cement Association (CNCA) has taken the lead in collaborating with Caltrans to secure approvals which includes moving from a non-standard special provision (nSSP) to approved standard specification language.

Both LCC and EPS blocks are widely accepted lightweight fill ground improvement strategies in the Caltrans Geotechnical Manual and have been used in practice for decades. However, mechanical and dynamic properties have rarely been characterized for LCC. CNCA has partnered with practicing LCC designers and contractors to conduct an extensive literature search through California State University – Fullerton. Academia will produce a document that highlights known properties of LCC and finds any gaps in design guidance in specifying such materials. Specific attention has been given to failure modes, modeling information, load transfer, and long-term performance. The collection of findings will be published,

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and more research will likely follow. The ultimate goal is to give agencies and designers the tools to better understand LCC behavior and bolster use of an emerging geotechnical solution.

Structures Design and Construction for the Historic Columbia River Highway State Trail: Wyeth to Starvation Creek Segments

Gary Conner • *Jacobs*
Michael W. Zilis • *Walker Macy**

The Historic Columbia River Highway, America's first scenic highway, was constructed between 1913 and 1922. Subsequent construction of a water level route in the late 1940s and early 1950s demolished portions of the original highway and left intact but abandoned and disconnected segments on the hillsides above. This resulted in the shoulder of Interstate 84 being the only bicycle and pedestrian route through the Gorge for several miles between Cascade Locks and Hood River. In the mid-1980s, state and national legislation directed the preservation and enhancement of the Historic Highway and the reconnection of these abandoned highway segments for use as bike and pedestrian trail. Since then, several projects have been constructed but the entire route has not yet been completed.

This trail segment, constructed between 2015 and 2019 under two contracts administered by FHWA Western Federal Lands, reconnects multiple segments of the old highway grade to open 4.3-miles of trail. The structures include 4 bridges, a wide variety of retaining walls and engineered slopes, rockfall protection fencing, and 5 styles of pedestrian rails. The design of these elements was guided by a 2010 State Trail Plan and a 2011 State Trail Guidelines Document prepared with the input of a variety of county, state, and federal agencies as well as several private advocacy groups. These documents provided input to the forms, materials, and surface treatments of all project structures through the guiding principals of capturing the natural beauty of the Gorge, respecting the design of the early highway designers, and considering the user's experience. These guidelines have resulted in a facility with character defining features that fit the natural environment; often reflect, but sometimes contrast, the historic highway structures adjacent historic structures; respect scenic vistas both from and towards the trail; and meet current design criteria.

To meet the trail aesthetic guidelines, the structures incorporate precast and cast-in-place integrally colored concrete, galvanized steel treated with a weathering agent to darken the surface, stone masonry, riprap, and painted timber. Structural elements incorporating these items will be presented, including pedestrian rails with precast balusters, overlook balconies cantilevered over the edge of walls, stone masonry pedestrian rails with arched openings, and architecturally congruent expansion joints and seismic restrainers. The presentation will include the factors that led to the selection of very different pedestrian rails - architectural concrete, massive stone masonry, weathered steel, or painted wood - at various locations. The creative use of micropiles, ground anchors, rock dowels, and rock bolts for efficient bridge foundation and retaining wall design in this highly variable and unstable hillside environment will also be discussed, including modifications implemented during construction due to unforeseen conditions.

7D INNOVATIONS

Design Challenges of a Cut-and-Cover Tunnel Widening

Brad Wilton • *T.Y. Lin International*
Patrick Wilson • *Earth Mechanics, Inc.**

T.Y. Lin International is providing preliminary engineering, final design, bid support services during construction, and design services during construction for the Division 20 Portal Widening Turnback Project. The project will enhance the Los Angeles County Transportation Authority's (Metro) Purple Line service operations and is a required component of the Westside Purple Line Extension Project.

Currently, the Metro Red and Purple Lines carry over 140,000 passengers each day. Ridership is expected to grow by 49,000 following the completion of the Purple Line Extension. To increase train speeds and ensure the reliability of operations, the existing tunnel portal is proposed to be widened and the tracks reconfigured as part of the turnback.

The portal structure is being coordinated with the Southern Regional Railway Association's (SCRRA) LINK-US project team, as well as with California High-Speed Rail (CAHSR) Authority to ensure all future rail lines are feasible in the future. The portal structure is 230′ in length, is comprised of reinforced concrete walls and an invert slab (U-Section) which will support the direct fixation trackwork and service walkways. The tops of the walls will serve as abutment seats for precast-prestressed-concrete box beams which span and cover the trench in this section. These beams will support waterproofing, asphalt concrete paving, and a 30′ embankment for the LINK-US project. The covered U-Section is up to 70′ wide and reaches a maximum depth of 30′ below grade.

The project is located in an area of high seismicity, with design PGA of 0.31g and 0.9g for the Operational Design Earthquake (ODE) and Maximum Design Earthquake (MDE), respectively. Site soils are competent for structural support but are susceptible to significant horizontal shear strains during earthquake shaking. These shear strains contribute to differential ground movements between the top and bottom of the portal, which will impose racking deformations on the underground structure. In addition, the inertial response of the overlying 30′ LINK-US embankment will influence its seismic racking behavior. In order to evaluate the seismic response of the ground-portal system, dynamic nonlinear finite element (FE) analysis was performed by the geotechnical consultant, Earth Mechanics Inc. A two-dimensional model was developed which included the portal structure, the surrounding soils, and 30′ embankment. Project-specific earthquake time histories

*Co-presenter; **Co-author

were generated and applied as inputs at the base of the model. The FE analysis modelled nonlinear soil layers with the effective properties for all concrete structure elements.

The MDE forces from the FE analysis greatly exceeded the practical non-yielding capacity of the walls. Therefore, a nonlinear pushover analysis was performed to show there is adequate non-linear displacement capacity of the structure in the MDE case. The forces from ODE case governed portions of the design. The requirements of the ODE event required essentially elastic behavior of the pipe shear pins which connect the box beams to the U-Section walls. The shear pins were designed to remain essentially elastic for ODE displacements and the axial strut forces from the box beams.

Construction is anticipated to commence in 2019 and be completed in 2023.

Moving Forward from Failure: Adhesive Anchors

Tanarat Potisuk • *Oregon Department of Transportation*

Use of post-installed anchors with sustained tension loads had been limited by Federal Highway Administration due to the ceiling panel collapse in Boston, MA in 2006. Adhesive anchors provide higher capacities than other post-installed anchors. However, creep under sustained tension loads was found to be the cause of the ceiling panel failure incident along with irregular installation of the anchors. Adhesive anchors were prohibited for use under sustained tension loads by FHWA not long after the incident. As a result, very few options were available for post-installed concrete anchoring under sustained tension load situation.

A Technical Advisory regarding use of adhesive anchor under sustained tension loads was issued in January 2018. According to the Technical Advisory FHWA recommends that post-installed adhesive anchors can be used for resisting sustained tension loads only if specific requirements are met. The recommendations were based on two National Cooperative Highway Research Program (NCHRP) studies, American Concrete Institute (ACI) publications, and the industry work. Recently, anchoring to concrete design guidance was added to Section 5 of the AASHTO LRFD design specifications, which refers to the ACI building code. The new requirements apply to all new Federal-aid projects. For existing adhesive anchors FHWA recommends that an inspection program should be instituted by owners to ensure good long-term performance of already installed adhesive anchors resisting sustained tension loads. Where inspection cannot confirm performance of adhesive anchors, the anchors should be replaced.

Since 2006 ODOT has been aware of the creep issue and has made it clear that when post-installed adhesive anchors are used for sustained tension loads, load magnitude must be kept very small in design. ODOT developed its own design equations, approved a number of adhesive products to be on the qualified product list (QPL), and required testing during anchor installation in construction projects to ensure properly installed anchors. However, with the new recommendations from FHWA some of these policies require adjustment including bridge inspection procedures. The new ODOT design guideline for adhesive anchors uses ACI design equations, but with design parameters obtained from epoxy manufacturers on the QPL resulting in efficient design of post-installed adhesive anchors. These steps taken by ODOT ensure qualified anchors are properly designed, installed, and monitored.

This presentation will describe the background, how ODOT laid out the task plan, and proceeded accordingly. It will explain which policy documents were revised to ensure adhesive anchors resisting sustained tension loads are in compliance with the FHWA recommendations. The presentation will be useful for other State Agencies as well as the bridge design and construction community.

10' Diameter CMP Replacement Under High Fill with In-Place Tunnel Liner

Jonathan Tronson • *Burns and McDonnell*
Darren LaMay • *Idaho Transportation Department**
Tom Greer • *Burns and McDonnell**

US-30 PORTNEUF RIVER CMP REPLACEMENT

A recent culvert replacement project in southeast Idaho used partial tunneling with tunnel liner plate to replace a severely deflected CMP in the Portneuf River under US-30. This trenchless replacement method was selected to replace the 262-foot-long, 10-foot-diameter culvert because of multiple project constraints, including tall MSE retaining walls with 45 feet of fill and geofoam above the culvert. Other trenchless alternatives considered included liners and jack & bore. This presentation will cover the project's initial evaluation, design alternatives, constructability, industry engagement, specifications, and environmental issues.

The project is located between McCammon and Lava Hot Springs, Idaho, where a 1962 flood had washed out the main channel culvert and caused the roadway embankment to fail. At that time, the Idaho Transportation Department put the culvert back in place and added two 10-foot-diameter overflow culverts to handle future floods. Over time, the overflow culverts' inverts corroded, and a portion of the main channel culvert crown became significantly deflected into a kidney-bean shape. In 2011, the Topaz Bridge and US-30 widening was constructed, which replaced the bridge over the Union Pacific Railroad and the Marsh Valley Canal. Geofoam fill and MSE walls used in that project presented challenges for the culvert replacement. Environmental constraints included wetland impacts and mitigation, aquatic organism passage, presence of migratory birds and bats, protection of vegetation, and turbidity. Hydraulics challenges included demonstrating a no-rise, obtaining acceptable velocities, and avoiding a decrease in the hydraulic opening. In addition, the Portneuf-Marsh Valley Canal Company limits the timeframe for reducing river flows with an upstream flow control structure to October through March, when low flows are anticipated.

The Idaho Transportation Department partnered with Burns & McDonnell to solve this complex problem. Early in the project, it became clear that a simple slip liner solution would not produce the desired results, and an alternate solution was necessary. The team studied other trenchless alternatives, including liners and jack

** Co-presenter; ** Co-author*

& bore, but the deflected shape of the existing culvert limited the size of liner that could fit in the available opening, and the resulting changes to flow lines and velocities were unacceptable. The team identified three possible alternatives: traditional jack & bore, jacking a larger pipe around the existing one, and partial tunneling. Both jacking alternatives would require construction of a substantial and expensive bulkhead in the river channel and would impact the surrounding MSE walls, potentially conflict with the geofoam fill, and increase the construction schedule. Ultimately the partial tunneling alternative was selected because it could be constructed in-place and would produce acceptable hydraulic results, limit environmental impacts, and avoid conflicts with the MSE walls and geofoam fill. The partial tunneling alternative included shoring of the existing culvert, sequentially removing sections of the existing CMP, constructing a new pipe inside the existing one using galvanized steel tunnel liner plate, and timely pressure grouting of the new culvert sections. Additionally, all culverts were retrofitted with a beveled headwall to improve hydraulics, and the overflow culverts' inverts were repaired with concrete as preventative maintenance.

8A BRIDGE PRESERVATION

Proposed AASHTO Historic Bridge Preservation Guide Specification

Ray Bottenberg • *Oregon Department of Transportation*

A new Historic Bridge Preservation Guide (HBP Guide) has been created in cooperation with the AASHTO Technical Committee on Bridge Preservation (T9). This HBP Guide was approved by the AASHTO Committee on Bridges and Structures in June, 2019. The HBP Guide documents the cmTent state of practice for the design of historic bridge preservation projects, to improve highway agencies' ability to deliver historic bridge preservation projects successfully, to improve highway agencies' ability to manage historic bridge preservation programs, and to reduce personal liability exposure for bridge designers by more clearly defining "scope of employment" and "industry practices" for historic bridge preservation projects. Some highlights include:

- Good practices for successful interaction with State Historic Preservation Officers and other stakeholders.
- Appropriate design standards for historic bridge preservation projects.
- Intended Level of Service; a level of service that is adequate for the reasonably expected use of the bridge in a paiiicular site and situation, but may not meet all contemporary standards.
- Refined analysis methods, especially pertaining to load rating, scour issues, and unknown foundations.
- Common repair techniques used in historic bridge preservation.
- Treatments used to improve bridge durability.
- Innovative technologies developed and employed by many highway agencies in the U.S.
- Treatment of temporary works commonly used in historic bridge preservation projects.
- Numerous options available for treatment of historic bridge rails.
- Cost savings that can sometimes be achieved in conjunction with historic bridge preservation. Similarly, historic bridge preservation can sometimes significantly reduce environmental impacts and traffic impacts.

This presentation will introduce the HBP Guide to the bridge design community and familiarize bridge designers with its contents and features.

When Concrete Isn't Concrete: Preserving the Dry Canyon Bridge

Rebecca Burrow • *Oregon Department of Transportation*

The bridge over Dry Canyon on the eastern end of the Historic Columbia River Highway was constructed by state forces in 1920-21. At the time of its construction, no highway yet reached this rocky bluff overlooking the Columbia River. Camping at the exposed site, the construction crew was forced to deal with harsh weather and barely passable materials. Despite that they turned out a bridge which has survived nearly 100 years and, with its recent rehabilitation, is expected to last 100 more. Design for the rehabilitation project involved addressing extremely low strength concrete and high amounts of concrete carbonation, a degradation process where concrete reacts with CO_2 losing its ability to protect the reinforcing steel inside. The recently completed project addressed these issues by patching the concrete using unique techniques and materials and then realkalizing the concrete, a process that had never before been conducted on a bridge in the United States. This presentation will examine the decision making process that led to this unique rehabilitation and then discuss the lessons learned during the project.

WSDOT's Bridge Deck Preservation Plan for Notable Large Bridges

DeWayne Wilson • *Washington State Department of Transportation*

This presentation will provide a summary of WSDOT's bridge deck preservation plan for some of WSDOT's notable large bridges. WSDOT has a comprehensive Bridge Deck Program with the primary goal of preserving bridge decks to prolong their lifespan and avoid expensive deck replacements (sustainability).

WSDOT manages 3,322 vehicular bridges over 20 feet in length as part of the state highway system including some unique notable bridges. Bridges to be highlighted in the presentation include: The I-90 Denny Creek Viaduct built in 1979 (WSDOT first segmental post-tension box girder); The SR397 Ed Hendler Columbia River bridge built in 1978 (first cable stayed with post tension box girder bridge in the USA); The I-5 Ship Canal bridge built in 1962 (Steel Deck Truss with double decks on the mainline and the express lanes); The US-2 Ebey Island bridge built in 1968 (WSDOT's longest bridge).

** Co-presenter; ** Co-author*

WSDOT uses a variety of overlay types (Modified Concrete, Polyester and Asphalt with membrane) to preserve concrete bridge decks. WSDOT has established protocols to choose between these overlay types depending on a bridges deck condition, location and traffic volumes.

8B SUBSTRUCTURE AND SEISMIC DESIGN

Post-Earthquake Functionality of ABC Bridges with Column Connections with Self-Centering Capability

Bijan Khaleghi • *Washington State Department of Transportation*

The current seismic design practice requires normal bridges to meet the Safety Evaluation Earthquake (SEE) and Functional Evaluation Earthquake (FEE) for Essential and Critical bridges as specified in Table 1. Seismic Hazard Evaluation Levels and Expected Performance

Expected Post-earthquake Service Levels are categorized as:

1. No Service – Bridge is closed for repair or replacement
2. Limited Service –Bridge is open for emergency vehicle traffic with reduced number of lanes for normal traffic is available within three months of the earthquake; and
3. Full Service – Full access to normal traffic is available almost immediately after the earthquake.

Bridges subjected to the seismic hazard levels shall satisfy the displacement criteria specified in LRFD-SGS as applicable and the maximum displacement ductility demand values as appropriate to the Seismic Hazard Evaluation Levels and Expected Performance.

The primary seismic design objective for standard bridges has been collapse prevention. Collapse prevention is certainly necessary but insufficient with respect to the overall performance of the highway network and its post-earthquake serviceability. Therefore, bridges within the seismic resiliency routes (Lifeline) need to first resist seismic forces and displacement demands during earthquakes, and second is to remain operational with minor repair after earthquakes.

In recent years the ultra-high performance concrete (UHPC) has been tested for bridge columns to improve to improve the performance of the connection within the plastic hinging regions. UHPC with its superior properties of higher compressive strength and modulus, and very low permeability, can provide improvements over conventionally build bridge columns.

This paper focuses on the seismic performance precast bridge columns meeting the two level seismic hazard evaluations SEE and FEE requirement using a combination of UHPC for column plastic hinging regions in combination with super-elastic materials (shape memory alloy) or self-centering capability (unbonded center prestressing) to achieve seismic resiliency during earthquake and full or partial operation immediately after the earthquake.

Innovative Ductile Seismic Shear Keys

Majid Sarraf • *Michael Baker International*

Prediction of seismic demands with using conventional shear keys which can have a brittle (rigid-fail) response are difficult. Thus, lack of reliable mechanism in conventional shear keys can lead to underestimation of seismic displacement demands in adjacent columns. This is due to the fact that inherent physical constraints in deformation capability of conventional shear keys lead to their lack of ductility and total failure under larger displacement imposed on them as with the adjacent columns. Such behavior is also difficult to model in a tradition elastic dynamic model of a bridge for predicting seismic displacement demands. This presentation will first provide a summary of the challenges with current bridge seismic design practice in the context of analysis assumptions, seismic displacement demands and design of shear keys, then describe the innovative details for a new "Ductile Seismic Shear Keys" along with governing principal of ductility by the author. This fundamentally superior approach in seismic design and criteria for shear using "Ductile Shear Keys" is presented for Dixon Landing Bridge—a representative of a typical two-span concrete bridge. The stiffness, strength and ductility values in design and detailing of shear of this Ductile Seismic Shear are use. It is demonstrated that when this innovative shear key is used it not only prevents premature abutment pile failure but can reduce seismic displacement demands by 30%.

Trancas Creek Bridge Replacement Project

Ahmadreza Mortezaie • *California Department of Transportation (Caltrans)*

Shiva Karimi • *California Department of Transportation (Caltrans)***

The existing Trancas Creek Bridge is located at State Highway Route 01 Postmile 56.5/56.9 in Los Angeles County. The bridge was originally built in 1927 and was later widened in 1938. Currently, it is 97 feet long and 85 feet wide and has three spans all supported on spread footing. The bridge supports have sustained continual scouring, resulting in distress, and is the cause for urgent bridge replacement.

The existing bridge will be replaced with a new four-span bridge that is 240 feet long and 90.5 feet wide and will be supported by two abutments and three bents. Each span is 60 feet long between its supports and will be supported by six (6) three-foot diameter cast in steel-shell (CISS) piles at each bent location and twelve (12) two-foot diameter CISS piles for each abutment foundation.

** Co-presenter; ** Co-author*

The bridge site is mapped within the "susceptible to liquefaction" seismic hazard zone, as well as tsunami inundation zone with groundwater at an approximate depth of 10 feet from the existing ground. Furthermore, as indicated by the analyses using the recently conducted exploratory borings and CPT soundings conducted at the site, the underlying soil includes relatively thick liquefiable soil layers and therefore, lateral spreading with large displacement at the site is expected. The liquefaction-induced lateral spreading and the consequent loads and deformation demands on the bridge foundations and abutments played a major role in the design process of the foundations, and especially the CISS piles.

The paper in-hand describes the site exploration findings, engineering analyses, and design procedures for the abutments and the bents' CISS piles' design, particularly given the lateral loads and deformations due to the liquefaction-induced lateral spreading.

8C UNIQUE BRIDGE SOLUTIONS

Construction of the Lewis and Clark Cable-Stayed Bridge Over the Ohio River

Marcos Loizias • *Jacobs*

Constructed under a $780 million public private partnership contract (P3) the Lewis and Clark Bridge features a 2,280-ft long three-span symmetrical steel composite cable-stayed bridge with a center span of 1,200 feet and back spans of 540 feet each.

The towers supporting the bridge feature convex curved diamond configuration and are supported on waterline footings founded on eight-foot diameter drilled shafts socketed into competent limestone. The superstructure features a streamlined steel composite deck consisting of inclined longitudinal steel I-shaped edge girders at each end and transverse floor beams made composite with the precast concrete deck. A minimum 2″ thick concrete overlay is placed atop the precast panels to provide for greater durability of the bridge deck.

The cable-stayed bridge has a total of 104 parallel strand stay-cables, spaced at 45′-0″ intervals at the edge girder anchorage, and arranged in a modified fan arrangement. The stay-cables are connected to the edge girders using in-line shark-fin anchorages welded directly to edge girder web to provide for direct load path of the cable forces into the girder. At the tower head anchorage, the cables are anchored into steel anchor boxes.

To meet an aggressive schedule required by the Concessionaire towards earlier collection of toll revenues, the construction of the bridge was accelerated through early staging of the superstructure steel grillage in both the back spans while completing construction of the towers. The steel grillage for the Kentucky back span was stick-built, while for the Indiana back span it was incrementally launched into position in a unique such application in a cable-stayed bridge project. The launching process entailed erecting the steel grillage in an assembly area behind the abutment and then progressively pushing the assembled grillage in 3 stages out over temporary roller bearing supports and into its final position between the tower and the anchor pier. Following the simultaneous completion of the two back spans and the towers, the center span construction proceeded in balanced cantilever constructing the two tower cantilevers simultaneously. 104 stay-cables were erected and the center span steel grillage and the 2,280-ft long cable-stayed deck (over 800 precast panels) constructed in record time of only five months.

The bridge opened to traffic on December 18, 2016. The project owner is the Indiana Finance Authority. The P3 contract, covering the financing, design, construction, operation and maintenance of the bridge for 35 years, was awarded to a consortium consisting of Walsh Investors, Bilfinger Project Investments and Vinci Concessions with Walsh Construction Co. and Vinci as contractors, and Jacobs as the Lead Design Engineer

The presentation will discuss the methods of construction for the substructure, towers, and the superstructure of the cable-stayed bridge.

Elkhorn Drop Ramp Structure

Percy Penafiel • *Nevada Department of Transportation*

Lessons Learn during the analysis, design and construction of the first T-Bridges Intersection in Nevada. HOV direct access to Elkhorn Road required a T-bridges intersection on Elkhorn Road. The base design is a three way "T" signalized intersection. Eastbound Elkhorn Road has two thru lanes and one shared thru-right. Westbound Elkhorn Road has three through lanes and one left turn lane in the existing median. Existing condition has no intersection, three lanes in each direction, and pedestrian facilities on both sides of the roadway with a 12′+ median. The project connects some median ramps (direct connect HOV ramps) to the bridge and form an intersection. Base design includes one left turn lane and one right turn lane on the Elkhorn road direct connect HOV off-ramps. The direct connect HOV on-ramp is one lane. All approaches to the intersection are signal controlled.

Keller Ferry Landings Project

Amy Leland • *Washington State Department of Transportation*

The North and South Keller Ferry landings are unique structures that support the only state ferry system in Eastern Washington. Not only do the landings float, but they are also designed to move almost 800 feet horizontally along a concrete ramp to accommodate the large variance of water level in the Franklin D. Roosevelt Lake where they are located. This lake is the reservoir held behind the Grand Coulee Dam, and the water level can fluctuate 80 feet throughout each year.

One end of each landing is supported by a series of prefabricated pontoon units. The shore end of each landing is supported by hollow steel rollers. A cable system is used to hold the landings in place. The vessel itself aids in moving the landings up and down the ramp.

** Co-presenter; ** Co-author*

Due to deterioration in the existing pontoon units a replacement was required. However, a lot of the mechanical and electrical equipment on the landings had recently been replaced, and the transfer of this equipment rather than replacement was desirable. The re-design of the Keller Ferry landings sought to provide long term operation of the landings and eliminate some of the maintenance and operational issues. One operational concern involves restrictive angle points between the vessel deck, the landing deck, and the approach ramp. Modifying some of the deck elevations and slightly lengthening the structure improves the angle points. Another concern was the transport of the North landing. The landing has to move to a secondary location every year when the water level is low. Topographic ramp constraints require the use of two separate landing locations

Floating of the landing during transport was to be achieved without the aid of an external flotation device. Due to this requirement, the transition span between the pontoon units and the shore was designed as a closed box system. The closed box would act as another pontoon unit and provide enough flotation to safely move the landing from one location to another.

Another unique component to the design was the vessel support cradle. Being a floating structure, the landings displace vertically when loading and unloading truck traffic. Since the vessel itself can trim quite a bit due to truck loading, a vessel support cradle was designed to help share the live loads between the vessel and the landing structure.

The out of service time for the ferry route is limited to 14 days total during construction due to long detours. Although a lot of the structural components are new, a few items such as the aprons and their supports, along with the mechanical and electrical equipment, are to be transferred from the old to the new landings. Precise coordination is required to keep the closure to a minimum.

This presentation will address the operational and design challenges encountered, and the resulting design solution. The contract has recently been awarded, and construction is expected to be complete by September 2019.

8D STEEL BRIDGE TOPICS

AASHTO-NSBA Guidelines for Resolution of Steel Fabrication Errors

Heather Gilmer • *HRV Conformance Verification Associates, Inc.*

No abstract provided.

Steel Girder Heat Straightening from Impact

Tyler Thomas • *Flame-On, Inc.*

No abstract provided..

New and Exciting Changes to Welding for Bridges

Ronnie Medlock • *High Steel Structures*

No abstract provided.

9A INNOVATIVE SOLUTIONS

Use of Cone Penetration Test (CPT) in Design of Bridge Foundation Piles Subject to Liquefaction

Sharid Amiri • *California Department of Transportation (Caltrans)*

A case study in California for design of bridge pile foundation subject to liquefaction, using Cone Penetration Test (CPT) supporting a multi-span Cast in Place Pre-Stressed Concrete Box Girder structure is presented. The bridge foundation consists of steel pipe piles. The following key design issues were evaluated:

1. Site specific liquefaction potential
2. Liquefaction induced settlement
3. Seismic downdrag
4. Lateral capacity of the piles subject to liquefaction.

The case study offers a valuable insight into the importance of using CPT in design of bridge foundation subject to geoseismic hazards.

Latest Advances in Large Span Flexible Buried Bridges

Joel Hahm • *Big R Bridge*

Buried bridges are bridge structures (>20 ft span) consisting of a buried structure that works with engineered granular backfill to support design loads through soil-structure interaction. Flexible buried bridge structures typically consist of deep corrugated galvanized steel structural plate structures and are used as an alternative to conventional bridges for a wide range of DOT, mining, rail, public works, environmental, and private projects. Over the past 20 years there have been significant advancements and improvements in analysis, manufacturing, and materials that have resulted in an increase in structure spans, load carrying capabilities, and possible applications. As a result, buried bridges are becoming an increasingly popular alternative for many conventional bridges. Local, state, and federal agencies have limited in house knowledge and expertise of how to design buried bridge structures and properly develop and specify them for their projects.

** Co-presenter; ** Co-author*

A workshop titled Latest Advances in Large Span Buried Bridges took place on January 13, 2019 at the 2019 TRB Annual Meeting in Washington, DC to highlight applications and advances in large span buried bridges (generally >50 ft span). This presentation will include several case studies presented in that workshop and discuss how large span flexible buried bridges are being used as an alternative to conventional bridges. Topics to be incorporated into discussions include ABC advantages, resilience, durability / service life considerations, design considerations, value engineering / project development, specifications, load rating, seismic considerations, and other topics.

Mr. Hahm is a recognized leader in the design and development of flexible buried bridge projects. He provides training and educational resources on buried bridges through workshops and seminars for various organizations nationwide and is the current chair of the TRB Subcommittee on Buried Bridges (AFF70-1).

WSDOT Ferry Terminal at CColman Dock – Pedestrian Bridge Utilizing Innovative Materials for ABC

Geoff Swett • *Washington State Department of Transportation*

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9B BRIDGE REHABILITATION AND INSPECTION

Rehabilitation and Deck Replacement of the Columbia River Bridge at Umatilla

Anthony Mizumori • *Washington State Department of Transportation*

This presentation will share WSDOT's experience on the design and construction of a $9.5M bridge rehabilitation project including the following topics: bridge deck replacement, lightweight concrete, fiber reinforced concrete, steel repair, bridge jacking, bearing replacement, condition inspection, ultrasonic testing, corrosion resistant steel, and construction lessons learned.

The main spans of the Columbia River Bridge at Umatilla, which carries southbound traffic on I-82 from Washington State to Oregon, are supported by a 1,920 foot long cantilever steel truss. The original bridge had a lightweight concrete deck that had deteriorated significantly due to severe exposure since its original construction in 1955. Bridge maintenance crews had routinely installed fully depth deck patches. The rehabilitation project included a deck replacement using lightweight concrete, epoxy-coated and stainless reinforcing steel, and a synthetic fiber reinforced bonded concrete overlay. Performance mix specifications were used for the lightweight concrete to ensure a high level of durability, and this was WSDOT's first implementation of polypropylene fiber-reinforced concrete. The presentation will address challenges in designing compact connections in lightweight concrete with epoxy-coated reinforcing steel, challenges using pre-saturated lightweight aggregate, and challenges achieving bond in a fiber reinforced concrete overlay.

Years of service and regular use of deicers have also led to degradation and wear in the steel anchor bearings, wind shear locks and expansion devices, many of which were rehabilitated. Prior to contract, the condition of anchor bearing linkages were evaluated extensively using phased-array ultrasonic testing, and replacement was ultimately selected. In order to replace the bearing linkages, the ends of the truss were lifted using a high-strength bar jacking system. Also, structural stainless steel was used in key places of the steel repairs to extend service life at high-wear interfaces.

The original bridge was designed as an efficient determinate cantilever truss, so restrictive construction sequencing requirements were needed to prevent bearing uplift and overstress of truss members during the deck demolition and replacement work. The presentation will discuss the pre-construction engineering efforts and contracting challenges of these constraints. The contractor was the Max J. Kuney Company. Construction began in mid-2017 and concluded in mid-2019.

Overview of WSDOT's Bridge Deck Replacements on Prestress Girder Bridges

Andre' La Foe • *Washington State Department of Transportation*

This presentation will summarize WSDOT's bridge deck replacement history on Prestress Concrete Girder (PCG) bridges. WSDOT manages 3,322 vehicular bridges (over 20 feet in length) as part of the state highway system including nearly 1,250 prestress girder spans with concrete bridge decks. WSDOT has replaced concrete decks on seventeen (17) state owned bridges to date including six (6) on prestress girder bridges. WSDOT has a comprehensive Bridge Deck Program with the primary goal of preserving concrete bridge decks but in some cases, replacing a bridge deck is necessary based on advanced deterioration.

Early generation Prestress Concrete Girder (PCG) bridges were designed with a 5 ¾ inch deck thickness. All six of these bridge decks replaced to date had a thickness of 5 ¾ inches. This presentation will look at the similar details from these six bridges. WSDOT has 91 remaining PCG bridges with 5 ¾ inch deck thickness that may also require a deck replacement in the future.

Implementation of and Recommendations for AASHTO Guidelines for Complex Bridge Inspection

Brian Leshko • *HDR*

HDR was selected to provide technical guidance on complex bridge inspections. HDR has detailed experience and knowledge of some of the most challenging considerations encountered in the field inspecting complex bridge structure types including movable, suspension, cable-stayed, orthotropic deck, tied-arch, box girder, pin and hanger, etc. HDR also is experienced in developing inspection manuals and performing NBIS oversight nationwide for the FHWA on previous projects. The initial research collected information from bridge owners and engineers on procedures for complex bridge inspection. The collected information from the comprehensive literature review and survey was synthesized to provide the technical basis for the guidelines, which were developed as the project deliverable. These guidelines were submitted to the American Association of State Highway and Transportation Officials Subcommittee on Bridges and Structures (SCOBS) Technical Committee T-18, Bridge Management, Evaluation and Rehabilitation, for evaluation, decision and potential adoption. Upon completion of the project, HDR prepared a final report that documents the entire research effort. This report and the guidelines are available for downloading.

The objective of this research was to develop guidelines for complex bridge inspection to support State DOTs in preparing their own complex bridge inspection procedures that will comply with Metric 19 of FHWA's 23 Metrics. The proposed guidelines with commentary are intended to be incorporated into Section 4 of the AASHTO Manual for Bridge Evaluation or be presented as a stand-alone supplement to the AASHTO Manual for Bridge Evaluation.

The concept of bridges comprised of complex components will be introduced, discussed and compared with bridges comprised of fracture critical members/components and with bridges comprised of substructure units requiring underwater inspection. This concept will be further expanded upon with an example of how it was recently implemented to recommend which bridges in a specific DOT's inventory were to be categorized as "complex", "fracture critical" and requiring "underwater inspections", as part of their Bridge Inspection Guidance Document that HDR developed. The presentation will conclude with recommendations for the bridge inspection community regarding these "unique inspections", above and beyond routine inspections mandated in accordance with the NBIS.

9C SEISMIC PAST AND PRESENT

A General Overview of SDC 2.0 Changes to Caltrans Seismic Design Criteria

Christian Unanwa • *California Department of Transportation (Caltrans)*
Mark Mahan • *California Department of Transportation (Caltrans)**

Since publication of the first edition of Caltrans Seismic Design Criteria (SDC 1.0) in 1999, improvements in seismic design knowledge gained principally from post-earthquake damage investigations, Caltrans seismic retrofit program, better characterization of seismic hazards, and Caltrans funded research to address specific design and construction issues, have necessitated the updates reflected in succeeding versions of the Criteria. Caltrans Seismic Design Criteria, Version 2.0 (SDC 2.0) published in 2019 is the most recent of these updates, and reflects Caltrans net cumulative seismic bridge design knowledge up to the 2019 publication date.

With respect to the preceding version of the SDC (i.e., SDC 1.7), SDC 2.0 incorporates new design and analysis provisions, technical revisions, removal of obsolete provisions, clarifications, and editorial enhancements, including a new code-and-commentary format that delineates code information and provides associated commentary in a separate column to clarify and explain the technical basis of the provisions.

A major update in SDC 2.0 is the enlargement of scope to include the seismic design provisions for a class of standard bridges with enhanced performance requirements called Recovery bridges. Other features of SDC 2.0 include: (a) addition of an entire section devoted to slab bridges, (b) addition of provisions for Grade 80 reinforcement, axial load limits for seismic critical members, nonlinear time history analysis method, minimum volume of transverse reinforcement, lateral stability of piles and shafts, bearings, seismic expansion joints, and additional provisions for seismic detailing, (c) use of only the probabilistic criterion in the definition of design spectrum, (d) revisions and clarifications to subsections such as precast girders, load factors for shear design, P-effects, abutment and in-span hinge support lengths, embedment lengths and clearances for column reinforcement extended into type II shafts, and (e) adoption of a new soil classification system and a new abutment longitudinal stiffness model.

*Co-presenter; **Co-author

While fulfilling its function as California's bridge seismic design code, it is expected that users will find the current edition of the SDC to be more user-friendly.

The Use of U-Shaped Flexural Plates for Supplemental Damping in Seismic Resilient Bridges

Jared Cantrell • *Idaho State University*
Mustafa Mashal • *Idaho State University**
Ali Shokrgozar • *Idaho State University***

The U-shaped flexural plates (UFPs) were invented by Ivan Skinner, a New Zealand scientist, in the 1970s. In a UFP, the mild steel plate is bent into a "U"-shape. The legs of the UFP are connected between the elements that relative sliding is expected to occur during a seismic event. When one leg of the UFP slides relative to the other, the plate yields along the curved portion, and thus provides energy dissipation. UFPs have been studied as source of supplementing damping for rocking walls in the buildings. They have been implemented in actual structures located in seismic zones. The structures were made of timber and concrete materials. UFPs offer advantages such as simple fabrication, energy dissipation, easy installation, robust low-cycle fatigue performance, and cost-efficiency. In 2014, the UFPs were packaged in a mini dissipater configuration that could be used as external dissipaters in rocking bridges. The work done at the University of Canterbury in New Zealand explored the use of mini UFP dissipaters in dissipative controlled rocking (DCR) connections for precast bridge substructure systems. The world's first precast bridge with DCR connections was completed in Christchurch, New Zealand in 2016. The UFPs were made of mild steel plates. Given the advances in the world of bridge engineering, the Idaho State University has conducted experimental investigations on the use of novel materials such as titanium alloy and aluminum UFPs in addition to mild steel for design and retrofitting of bridge structures. The research in this presentation provides a new perspective on the use of novel and corrosion resistance/high strength materials as supplemental damping sources for bridges. The presentation includes experimental results from testing of the UFPs made of three different materials (mild steel, titanium alloy, and aluminum) under quasi-static cyclic loading. The advantages and dis-advantages of each material will be discussed. The potential of using novel materials and seismic resilient technologies will be presented.

The Evolution of Seismic Design Requirements for Oregon Highway Bridges

Albert Nako • *Oregon Department of Transportation*

For a long time Oregon was considered immune to major earthquakes. The lack of understanding the level of seismicity and the nonexistence of modern seismic design codes led to majority of Oregon bridges being built without any seismic design consideration. In 1958 ODOT started designing bridges for a horizontal force of 2-12% of structure weight, but this appeared to match more closely the wind loads rather than seismic demand at bridge sites.

Right after the Loma Prieta Earthquake, in 1990 ODOT adopted the 1983 AASHTO Seismic Design Guides. Seismic hazards associated with a 500-year return period earthquake stared being used for the highway structures. The main objective of seismic design back then was the life safety of traveling public.

In mid-80s, many seismologists started to believe on the potential threat from a Cascadia Subduction Zone Earthquake (CSZE). Research since then has confirmed that Cascadia has a long history of great subduction earthquakes. Geologic studies have uncovered evidence of the coastal subsidence, tsunamis, landslides, and liquefaction that were produced by past Cascadia earthquakes. Seismologists have calculated the potential magnitude and ground shaking under the most probable scenarios.

In wake of this discovery, ODOT decided to adopt the most advanced seismic design codes available for bridge design. In 2004, ODOT adopted a higher level of design ground motion (1,000-year return event) for use in combination with the "No-Collapse" (Life Safety) criteria and also began designing and mitigating for the effects of liquefaction on bridge performance. However, the "signature" development for ODOT's seismic design policy was probably the implementation of the "Operational" criteria for a 500-year return seismic event. Bridges designed since 2004 are based on ground motions, structural analysis, design detailing and liquefaction effects that are consistent with current design standards.

Continues studies and research sponsored by ODOT led to a better understanding of the seismic hazards from CSZE. In 2014, United States Geological Survey (USGS) released new hazard maps that reflected a more appropriate contribution of the CSZE on the probabilistic hazard maps. Additionally, ODOT worked closely with the Portland State University (PSU) and USGS for developing seismic hazard maps specifically for the CSZE. After a thorough evaluation of seismicity for our state, ODOT modified the seismic design requirements by adopting the 2014 1,000-year USGS maps for the "Life Safety" criteria and the "Full Rupture CSZE" for the "Operational" Criteria. These design requirements are well more "aggressive" than existing AASHTO seismic design guidelines.

Simultaneously, ODOT has been actively working on another front: developing seismic design criteria and a comprehensive plan for mitigating the existing vulnerable bridges. Both, the criteria and the project selection are very unique, especially when considering the hazard level and the level of impact of a seismic event like Cascadia Subduction Zone Earthquake.

*Co-presenter; **Co-author

K2 CLOSING GENERAL SESSION

UHPC: A Solution for Today and Tomorrow

Benjamin (Ben) Graybeal • *FHWA*

Ultra-high performance concrete (UHPC) has emerged as a compelling solution that addresses a suite of challenges and opportunities in the bridge sector. This class of concrete offers enhanced mechanical properties and exceptional durability, thus enabling UHPC to be used for anything from field-cast connections to rehabilitative bridge deck overlays to pre- and post-tensioned superstructure elements. With more than 200 bridges containing UHPC connections having been constructed from coast to coast in the past decade, State DOT's have become aware of the behaviors and advantages of this high-end fiber reinforced concrete containing a discontinuous pore structure. The presentation will provide an overview of UHPC and a window into the current state of the practice. The presentation will conclude with a look toward a future wherein UHPC is a commonly deployed solution that delivers efficient construction and a long service life.

The AASHTO Service Life Design Guide Will Be in Your Future

Tom Murphy • *Modjeski and Masters*

No abstract provided.

Model Based Design/Construction: "Planless" Delivery of Utah Bridges

Daniel Jensen • *Michael Baker International*

With the help of contractors, designers, and software manufacturers, Utah Department of Transportation (UDOT) has successfully advertised two projects where the 3D Bridge model is the legal document. The first being a three span prestressed concrete girder flyover and two single span steel sister bridges over Union Pacific Railroad (UPRR) and the second project being a three span prestressed concrete girder over existing and proposed UPRR with a curved roadway alignment. Project goals were to submit all documents for review and construction in a 3D model. Though this was previously completed for specific disciplines, no projects with structures included had been attempted. UDOT and the consultants concentrated on taking lessons learned from previous projects to understand how to incorporate all the information from a traditional plan set submittal into a model-centric document.

3D Bridge models increased the effectiveness for information to be communicated to the client and contractor. These models allowed us to visualize key items early in the project and address those issues. Because the legal documents are now the models, contractors and fabricators have been able to use the models directly in the field and in their native software. UDOT will also be able to use these models for their asset management and bridge inspection documentation. This will reduce the time and additional expense required for contractors to create these models from plan sheets.

During the design phase, decisions were made on how to best present the information that would be required in the final advertising. Information such as deck and girder geometry, support and foundation geometry, and even minor elements such as bearings and joints had to be displayed correctly within the solids model. Any additional property information was provided as attributes on those mentioned elements. An accurate reinforcement model was also provided within the concrete elements displaying all bends, spacing, and additional properties that would be useful.

The work being done in Utah will be the foundation for other DOT's and consultants to build upon. Workflows were developed and UDOT standard practices and procedures adjusted to align to 3D projects. For Instance, the review procedures and QC documentation for 3D modeling is very different than the "highlighting" process used on non-3D projects. New checklists and documentations were developed to make the review process possible.

A large emphasis was placed on ensuring that contractors could consume all the information being provided to them. To allow the model to be easily understood by contractors, the design team decided on Bentley OpenRoads Navigator model reader as the best option. It has been reported by the contractors that after an initial learning curve, the process of getting information from the model has been very simple.

The intent of this presentation is to step through the process that was taken to create the 3D structural models and how information was presented for review and submittals. Also, lessons learned and recommendations for future project development will be discussed.

** Co-presenter; ** Co-author*