INTEGRATION OF LIGHT RAIL ON THE I-90 FLOATING BRIDGE ACROSS LAKE WASHINGTON

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ABSTRACT

Installing light-rail transit across a floating roadway bridge presents many unique challenges, foremost of which is how to design the multidimensional moving joints at both ends of transition spans between the fixed and floating structures. In conjunction with the Puget Sound Regional Transit Authority's (Sound Transit's) East Link Extension Project, a technical solution to this technical challenge has been proposed, analyzed, modeled, designed and prototype-tested.

This paper describes the planning, execution and results of a full-scale prototype testing program of the proposed Curved Element Supported Rail (CESuRa) Track Bridge System, which is based on the relationship of curved rail supports in two independent planes that will adjust in response to the movements of the Interstate 90 (I-90) Bridge below them. The prototype CESuRa track bridges that were tested performed as well or better than expected, and the information gathered and lessons learned will greatly benefit the remaining final design, track-bridge fabrication and installation process.

The paper also discusses the anticipated performance of these track bridges on the I-90 structure in conjunction with the proposed direct fixation track system, fixed rail anchors, and sliding rail expansion joints to be strategically located across the 1.1-mile-long Homer M. Hadley Memorial Bridge, a.k.a. I-90 Bridge. Built in 1989, the I-90 Bridge is the fifth-longest floating bridge in world and carries three westbound and two reversible lanes of traffic between Seattle and Mercer Island, Washington. It will be reconfigured to carry four westbound lanes and the reversible lanes will be converted to light-rail transit.

Keywords: Light rail transit, floating bridge, track bridge, computer modeling, prototype testing

BACKGROUND

The Municipality of Metropolitan Seattle (Metro Seattle), created by local referendum in 1958, was the first regional agency to consider installing transit on a floating bridge across Lake Washington. Despite two failed voter initiatives in 1968 and 1970 (*1*) to build a rail rapid transit system in the Puget Sound region, Metro Seattle, and its successor agency King County Metro, continued planning for and studying rail rapid transit throughout the intervening years before the formation and voter-approval of Sound Transit in the mid/late 1990s.

A December 1976 Memorandum of Agreement (MOA) among King County, the Cities of Seattle, Mercer Island and Bellevue, Metro Seattle and the Washington State Highway Commission provided in part: "The I-90 facility shall be designed and constructed so that conversion of all or part of the [center] transit roadway to fixed guideway is possible." (*2*) In addition, the September 20, 1978 Record of Decision for the I-90 Bridge project specifically required "as provided in the MOA, public transportation shall have first priority in the use of the center lanes." (*2*)

A 1984 Metro study, conducted concurrently with the Washington State Department of Transportation's (WSDOT) final design of the I-90 Floating Bridge across Lake Washington, determined that it would be feasible to convert I-90 reversible lanes for light rail and developed a concept for installing rail transit across the future bridge. (*3*) Metro commissioned three engineering consultants – Raymond Kaiser Engineers, Tudor Engineering Company and John I. Williams, an architect from the Metropolitan Boston Transit Authority (MBTA) – working under contract to Metro to examine the feasibility of the future conversion of I-90 for light rail. Mr. Williams proposed a possible way of transitioning light rail track structure from the fixed to the floating spans of the I-90 Bridge; his initial proposed solution, which subsequently became known as the "3-beam" concept, addressed this technical challenge.

Completed in the late-80s, WSDOT's design and construction of the I-90 Bridge considered rail transit traversing the structure, but no specific provisions were built into the bridge design to help facilitate a future track installation. When Sound Transit initially studied installing rail across the I-90 Bridge in the late-90s, a refined version of the "3-beam" concept was considered most feasible. However, this concept had never been advanced past a conceptual design stage or tested even on a small scale.

About ten years later in 2008 the Washington State Legislature Joint Transportation Committee's (JTC's) Independent Review Team (IRT) recommended that a full-scale test be carried out of the prototype design of what had come to be known as "track bridge" rail joints. Sound Transit's 2010 Request for Qualifications (RFQ) for the I-90 Track Bridge System & Prototype Project, invited consultant proposals for a multi-phased project to plan, design, prototype test, fabricate and install eight track bridges – one on each of the two tracks at both ends of the east and west transition spans of the I-90 Bridge. While a refined version of the 3-beam concept was referenced as one possible approach, the RFQ invited proposers to offer other solutions.

In early 2011 Sound Transit selected a consultant team led by Parsons Brinckerhoff, Inc. (PB) (now WSP | Parsons Brinckerhoff) with Balfour Beatty (which at the time owned PB), SC Solutions, Inc., and the Transportation Technology Center, Inc. (TTCI) as principal subconsultants. Two initial activities occupied the first few weeks of the project – a literature search to identify any other possible technical solutions that might exist for installing rail transit across a floating bridge, and a technical workshop led by key members of the consultant team and also included key staff from Sound Transit and WSDOT.

The literature search identified and documented a variety of rail joint configurations for handling various bridge movements, primarily in one direction or axis of rotation. No existing rail joint was identified for handling the combinations of movements and rotation of a floating bridge. At the technical workshop held in April 2011, the 3-beam concept was discussed and an innovative alternate concept, referred to as Curved Element Supported Rail (CESuRa) Track Bridge, was introduced by Mr. Andy Foan, Chief Engineer of Balfour Beatty Rail (UK), one of two Balfour Beatty participants at the workshop. (*4*) Upon thorough analysis and evaluation in Phase 1 of the project, the CESuRa concept was determined to be superior to the 3-beam concept, particularly in for its ability to support multiple movements and rotations at the same time, and was selected to proceed into design and testing in Phase 2. (*5, 6, 7*)

INTRODUCTION

Several other technical papers have thoroughly described the function, design, and laboratory component testing of the proposed CESuRa Track Bridge System, which will not be re-iterated here. (*8, 9, 10*) Following a description of the existing I-90 Bridge movements and description of the CESuRa track bridge system, and proposed rail movement, this paper focuses on the planning, execution and results of the full-scale prototype testing program, which was completed in 2014, and discusses the anticipated performance of the track bridges on the I-90 structure. The East Link Extension I-90 Final Design is scheduled for completion in 2016 with start of construction anticipated to commence in early 2017.

Floating Bridge Movements and Description of the CESuRa Track Bridge System

A project-team-created 3D image of the I-90 Bridge below shows the proposed locations of the track bridges on the center roadway. It should be noted, however, that only 3 lanes of traffic are depicted on the mainline roadways in Figure 1, whereas WSDOT's so-called R-8A project will be adding a High Occupancy Vehicle (HOV) lane to the existing mainline roadways in each direction, which is not shown below.

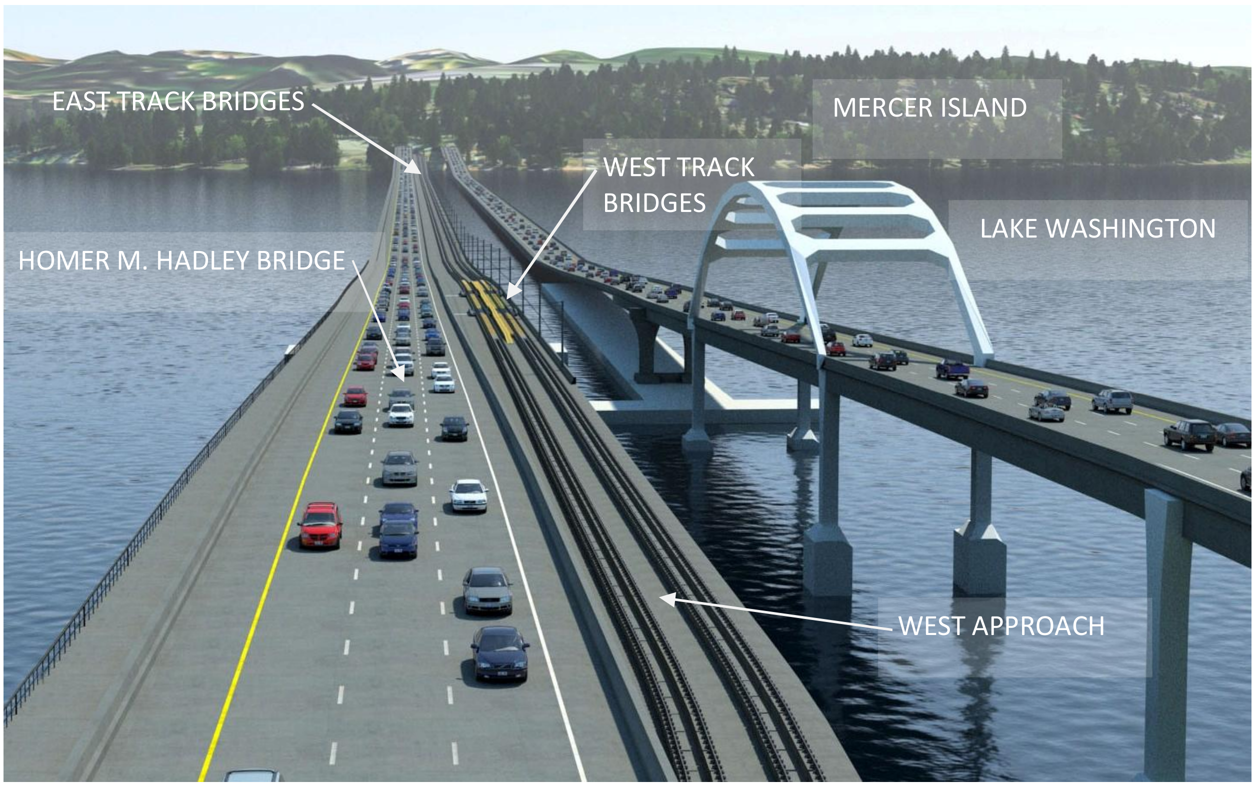
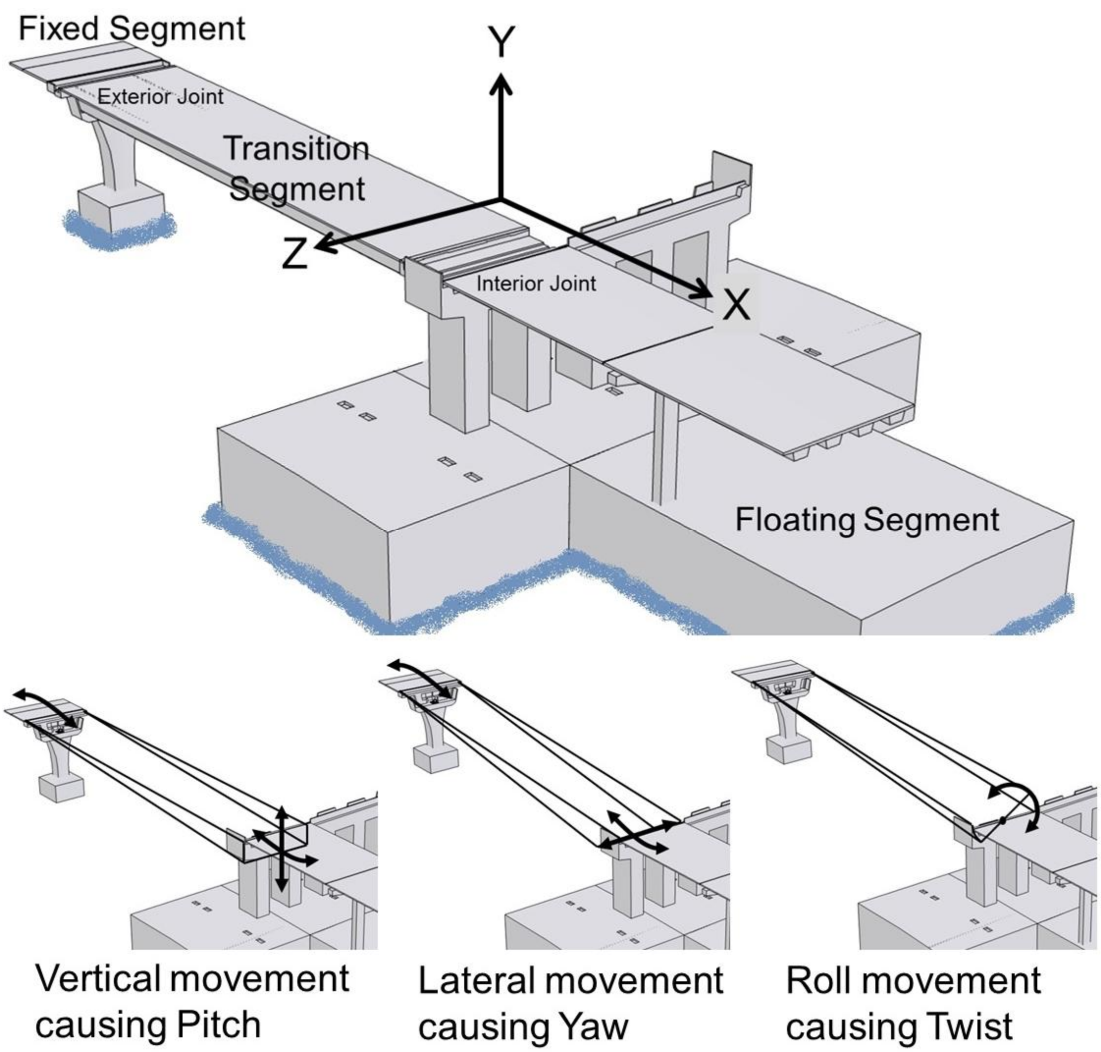


FIGURE 1 Proposed Locations of the I-90 Track Bridges and Structures.

The HMH Floating Bridge experiences the following normal movements as shown in Figure 2. The normal ranges of Roll, Pitch and Yaw are shown in parentheses below.

- **Surge -** longitudinal x-axis movement, passes through the pontoon from head to tail, and is applicable to the floating bridge structure and the track. Handled through rail expansion joints.
- **Heave -** vertical y-axis movement, passes through the pontoon from top to bottom, is applicable to the floating bridge span varying with lake level change and for the purpose of the track bridge design heave is incorporated as the rotation, Pitch.

- **Sway -** lateral z-axis movement, passes through the pontoon from side to side, is applicable to the floating bridge span varying with load and weather and for the purpose of the track bridge design sway is incorporated as the rotation, Yaw.
- **Roll (+/- 0.7 degrees) -** longitudinal x-axis rotation about x-axis and passes through the pontoon from head to tail, is applicable to the floating bridge span varying with load and weather.
- **Yaw (+/- 0.1 degree) -** vertical y-axis rotation about y-axis, passes through the pontoon from top to bottom and is a resultant of Sway.
- **Pitch (+/- 0.5 degrees) -** transverse or lateral z-axis rotation about z-axis, passes through the pontoon from side to side and is a resultant of Heave.



Orientation: X-axis, Longitudinal Y-axis, Vertical Z-axis, Transverse/Lateral

FIGURE 2 Bridge Axes and Movements.

Schematic features of the track bridge are illustrated in Figure 3. Spanning across the bridge (hinge) joints connecting the approach span and transition span bridge decks (and transition span and floating span decks) are two steel “wings” that form triangular secondary planes located such that they each have one (long) edge perpendicular to the hinge and a vertex near the hinge axis. On each wing a curved element is placed, called the “yoke.” The track is mounted on “bearer bars” which are supported on the yoke. When the hinge angle is zero and the wings are lying flat, an observer looking from the side in the direction of the hinge axis will see the yoke as a straight line. As the hinge angle increases, the wings will incline inwards as the long edges are forced upwards. The observer would then see a developing curvature as the yoke rises on the sloping wings and the bearer bars would appear to the observer to lie on a smooth yet continuously variable curve which is tangential at either end to the incoming/outgoing tracks. When the hinge angle is positive upwards, the track is in a segmental vertical sag curve. When the hinge angle is negative downwards, the track is in a segmental vertical crest curve. In this way, the track is supported across each moveable joint in a continuous and automatically-conforming alignment and profile.

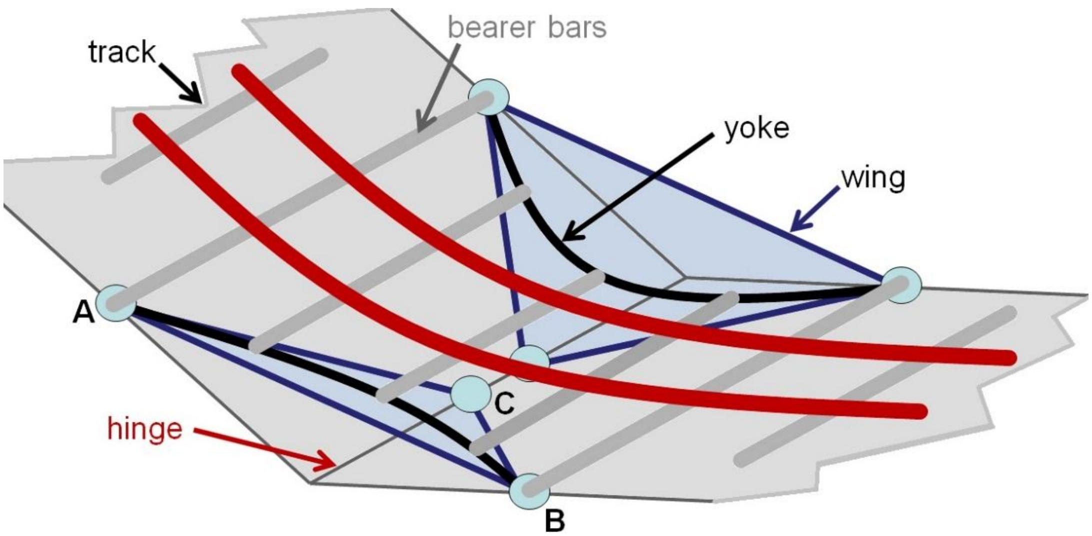


FIGURE 3 Schematic Features of the CESuRa Track Bridge.

The physical features and component locations of the CESuRa track bridge joint are illustrated in Figure 4. The rail and guard rail subsystems are supported on bearer bars using a longitudinally-free fastening system for the rails and pinned connections for the fabricated guard rails. There are seventeen variable length bearer bars, supported near the ends by friction pendulum bearings (FPBs) mounted in a curved pattern on a pair of wings approximately 42.5 feet long. Each wing (or triangular beam) is stiffened by an upturned edge beam and is supported by three elastomer bearings. This configuration allows the necessary bridge rotational and transverse movements but restricts undesired longitudinal movement. Two direct fixation (DF) track fasteners are bolted to each bearer bar to support the 115RE continuous welded (running) rails. Two 8-inch tall by 8-inch wide by ½-inch thick steel angle guard rails are also pinned to the bearer bars just inside the DF fasteners. The wing and edge beam is a continuous steel box fabricated from A572, Grade 50, welded steel plate as depicted in Figure 4. Constrained friction pendulum bearing bases are aligned on the wings along a curve and the set of bearings is referred to as the “yoke.”

Three steel laminated elastomeric bearing configurations are used to support each wing of the track bridges on the I-90 Bridge. Each bearing experiences rotational movements in multiple planes as the bridge moves, plus compression under traffic. The bearings at the transition span ends are allowed to slide longitudinally but are constrained laterally. In an extreme event, where the rotation and/or translation exceeds the bearing design limits, the bearings or mountings act as structural “fuses” by fracturing, protecting the bridge from damage.

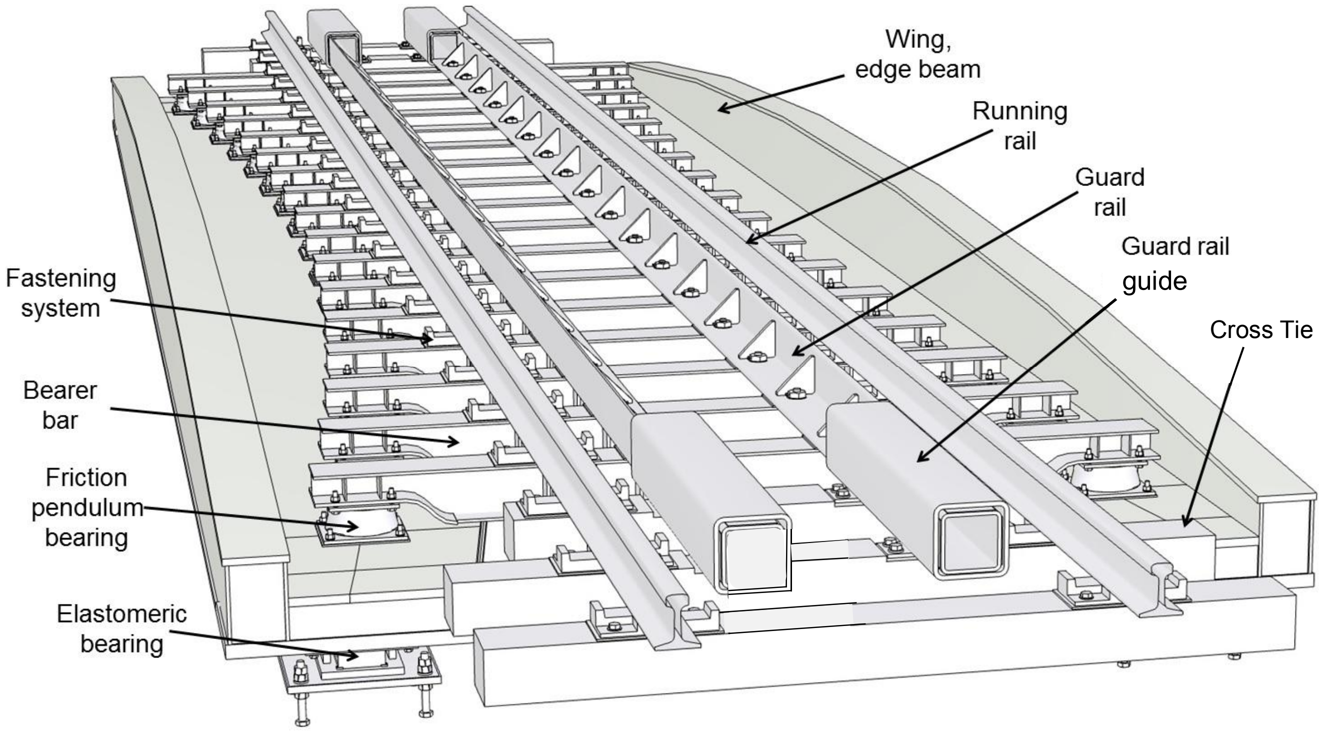


FIGURE 4 Features of the CESuRa Track Bridge.

The design utilizes longitudinally free fasteners on the track bridge. The rail clip is a tension-clamp that is bolted in place with plates and pads under the rail foot and between the rail and rail clip in order to permit "free" (low-friction) sliding of the rail with thermal and bridge movements. The rails will be free to move longitudinally over the track bridges to accommodate changes in Pitch and Surge. The design accommodates a lake level changes of +/- 18 inches from the median "neutral" position.

Proposed Rail Movement

While not an integral part of the track bridge, rail expansion joints will be installed on the first floating span to the lake-side of each Interior Joint. The running rails will be allowed to expand and contract to accommodate thermal and bridge movements from a double-crossover at each end of the approach spans through the track bridges to the rail expansion joints. Just inside of these rail expansion joints (towards the center of the bridge), fixed rail anchors will be installed and longitudinally-free fasteners will allow the running rail to move longitudinally between these anchors and sliding rail joints that will be installed on each track near the mid-point of the floating bridge. Since the track configuration is symmetric on the east and west ends of the bridge, longitudinal rail expansion and contraction will occur independently east/west about the mid-point of the bridge and between the double crossovers and the rail expansion joints.

FULL-SCALE PROTOTYPE TESTING

Purpose

From project inception in 2011, Sound Transit intended to conduct full-scale prototype testing in Phase 2 upon selection and design of the final concept. Full-scale testing was needed to confirm that the prototype design met the performance criteria contained in Sound Transit's Track Bridge System Technical Requirements (*11*) and to satisfy a Washington State Legislature, JTC requirement as recommended by the IRT. (*12*)

Test Facility

The full-scale testing carried out in Phase 2, starting in January 2013, was conducted at the Transportation Technology Center (TTC or Test Center) outside of Pueblo, CO. A unit of the American Association or Railroads, Transportation Technology Center, Inc. (TTCI) manages the Federal Railroad Administration (FRA) Test Center, located northeast of Pueblo. The facility offered an ideal location for constructing a specialized test track to replicate the I-90 Bridge profile and to plan and carry out a specialized testing program using the full technical resources of the TTC.

A customized 5,000-foot long test track, called the Sound Transit Test Track (STTT), configured as a track siding running parallel and connected to the west side of TTC's Transit Test Track (TTT), was designed by the consultant team as part of Phase 1 and built by Balfour Beatty Rail Infrastructure, Inc., in the spring and summer of 2013. Two full-scale prototype track bridges were fabricated by Jesse Engineering in Tacoma, WA and shipped to the TTC for installation, instrumentation, and testing. The STTT was electrified using a 1,500 Volt dc Overhead Contact System (OCS) supplied by an existing TTT traction power substation.

FIGURE 5 View of STTT looking north towards the Exterior Joint viewed from the cab of a test train over the Interior Joint. TB spacing and track geometry replicated the West Approach of the I-90 Bridge.

Testing Plan

Testing was conducted using the two full-scale prototype track bridges installed in the same configuration and vertical profile as proposed to be installed on the West Approach of the I-90 Bridge with the ability to adjust Pitch, Yaw and Roll. (See Figure 5) A detailed test plan was prepared by TTCI for PB and Sound Transit approval. Five main phases of testing were planned and executed: Baseline, Phase 1, Phase 2, Phase 3, and Phase 4, with adjustments made as necessary between phases. Each phase tested a different track geometry, to record track bridge member and rail strain (converted to stresses) and vehicle ride quality, as well as the effects of variations in simulated passenger loading.

Wayside noise measurements were also recorded with and without added noise dampening panels to determine whether they were needed or not. (It was determined that added noise dampening will not be needed.) All testing was carried out on or ahead of schedule.

Two Sound Transit LRVs were shipped to TTC for use in the testing. One of the LRVs was extensively instrumented to measure and record wheel, bogie, and carbody movement and acceleration. Following completion of the test track construction, testing began in August, 2013 with LRV dynamic clearance and OCS clearance tests and concluded in October, 2013 with braking and lateral tests. LRV runs were primarily conducted at the Sound Transit Link Light Rail 55-mile-per-hour (MPH) design speed and were conducted in each phase under simulated passenger loading conditions AW0 (empty) and AW3 (full passenger load).

FIGURE 6 Test train shown crossing the prototype Exterior Joint installed in the STTT.

Ride Quality

The vehicles' performance over the prototype track bridges was demonstrated to be well within the FRA track safety and rider comfort criteria for all bridge configurations from 5 to 55 MPH, confirming that the Track Bridge System could function at operating speeds of up to 55 MPH for design level I-90 Bridge movements. The Baseline case had the highest sustained vertical acceleration due to track deviations present during Baseline testing. Consistent with the acceleration measurements, analysis of the vertical ride performance and lateral ride performance were best with AW3 LRV runs. (*14*)

Lateral load tests were conducted in multiple configurations in order to simulate the lateral displacement the system is expected to encounter from 50 MPH winds on the train and to confirm that the track bridge will return to center after repeated displacements. Several lateral constraint configurations of guard rail were tested. All configurations worked satisfactorily. A pinned connection guard rail design detail was selected for the final design based on overall performance and potential for minimal maintenance.

Structural Performance (*13*)

Wayside information was recorded by TTCI on 450 channels throughout testing to observe displacement, rotation, acceleration, and strain. The track bridges were instrumented with gauges in 13 places to measure strain. The wings as a whole over-performed, exhibiting less stress than predicted by LARSA and ADINA modeling values for all channels. The maximum stress in the wings was observed in the center of the wing bottom plate at the edge beam connection, which is consistent with modeling behavior given this region is the least supported and heaviest region of the wing. The maximum strain in the wings throughout testing corresponded to a stress of 3.2 kips per square inch (ksi), which is well below the fatigue stresses in the 50 ksi steel.

Bearer Bar Performance

The bearer bars carry the wheel and axle loads from the LRV and into the track bridge. Their performance is critical to the overall performance and safety of the track bridge. Bearer bar stresses remained well below acceptable limits for Grade 50 steel (f_y = 50 ksi). Bearer Bar 17 on the Interior track bridge was the longest and was subject to applied rotations; it had the maximum stress of any of the bearer bars. The maximum live load deflection of the bearer bars was 1/4 inch.

Bearer bar stresses were also compared to those determined through finite-element (FE) modeling in ADINA. Comparing the maximum measured bearer bar stresses to those from the ADINA analysis and the patterns of stress overall it can be seen that bearer bar stresses are expected to remain substantially below maximum allowable stresses and that fatigue limits are not approached. Bearer bar stresses typical for all loading cases, range from 2 to 5 ksi.

Bearer Bar Lateral Movement

Bearer bar lateral movements were measured using bending beam instruments and were tracked for displacement on each run, noting that the incremental displacement from one run to the next was more important as an indicator of rail stress and LRV loading than the gross displacement. The maximum lateral displacement in the bearer bars was just under 0.25 inches, which is within the value suggested by Sound Transit technical and operational staff of 0.50 inches.

Rail Forces

The maximum vertical forces seen in the rail during AW0 testing were 12.52 kips and 12.62 kips at the Interior and Exterior track bridges respectively. For AW3 loading the reported vertical force values were 18.77 kips and 19.41 kips at the Interior and Exterior track bridges respectively. Longitudinal (X-direction) rail forces remained below 7.4 kips for AW0 loading and 11.0 kips for AW3 loading. Lateral forces (Y-direction) peaked at 6.2 kips for AW0 loading and 7.4 kips for AW3 loading. Based on FE modeling in ADINA, the maximum lateral forces (reported as transverse wheel forces) were up into the 8 to 9 kips range for Phase 3 AW3 loadings. This suggests that the ADINA models over-predict lateral forces in the system by 60% to 80%, suggesting a factor-of-safety between analysis and measured values of between 1.5 and 2.0.

Rail Stresses

Rail stresses followed a logical pattern given the progression of loading and the occasional high stresses resulting from very hot days on the test site during the month of September. Similar stresses were predicted by the ADINA model on the track bridge, in the range of +/- 5 ksi. Higher stresses were predicted between the track bridges by the ADINA models; in the worst case up to 27 ksi for AW3 loading running southbound in Phase 3 and in several other loading conditions spiking around 20 ksi. The rail between the track bridges on the STTT was Class 2 on ballast and so subject to an inherently rougher ride; this variation and the rail stresses between the track bridges (on the Transition Spans) are expected to be lower on the DF track on the I-90 Bridge. The maximum strains in the rail from testing correlate to a stress of 5.4 ksi at the Interior track bridge and 5.7 ksi at the Exterior track bridge. These values are much lower than the AREMA and Sound Transit allowable stress standard of 20 ksi and well below the specified minimum yield stress of 50 ksi.

Bearing Loads

Bearing loads were determined from the measured vertical displacement of the elastomeric bearings supporting the wings. Loads were then back-calculated from the displacements. The predicted loads, which were used for design of the elastomeric support bearings, were consistently higher than those measured. This relationship is a confirmation that the bearings are designed appropriately and that the predicted loads are well understood and will be conservative for deck and superstructure attachment design.

Rail-to-Earth Resistance Testing

Rail-to-earth resistance testing found that the system passed dry tests but initially not wet tests. Working with Sound Transit staff, the design team made track bridge modifications to address wet conditions. These modifications consisted primarily of providing insulating material between all steel-to-steel connections using material consistent with other East Link insulation, providing drip-producing covers to break connectivity and evaluating the value of an active current absorption system. When re-tested in the spring of 2014, the required 1-million-Ohms-per-fastener rail-to-earth resistance level was met or exceeded under both dry and wet conditions. (*13, 14*)

Noise Measurement

Noise measurement tests confirmed that noise exposure levels produced by LRVs crossing over the track bridges should be substantially below Federal Transit Administration noise criteria. (*14*)

IRT Issue Resolution

Responding to the technical issued raised by the Washington State Legislature's Joint Transportation Committee's Independent Review Team (IRT) was a critical objective of the full-scale prototype testing program. (*13*) Testing provided responses or input to the following IRT Issues:

- Issue A: Conduct Full-Scale Testing
- Issue A.2: Confirm (bearing) loads are verified by testing results
- Issue F: Provide multi-level stray current protection
- Issue M: Evaluate Rider Comfort on the Track Bridge
- Issue U: Identify Potential Stray Current Leaks

TESTING SUMMARY

The results of the full-scale prototype testing program confirmed the proposed design meets the Track Bridge System Technical Requirements, satisfied IRT recommendations, resolved related IRT Issues, and provided valuable experience in fabrication, installation, adjustment, and maintenance of the prototype track bridges. Maintenance operations conducted on the track bridges during the testing program did not require more time than typical track work maintenance. Changing out a friction pendulum bearing took approximately 45 minutes even though this component replacement had not been anticipated or rehearsed. Upon inspection, it turned out the FPB that was replaced was not flawed or defective in any way and could have remained in service, but the replacement process was demonstrated to be relatively simple. A complete report of the TTCI's Phase 2 Prototype Track Bridge Testing Program is available in Reference (*14*).

ANTICIPATED PERFORMANCE OF THE CESURA JOINTS ON THE I-90 BRIDGE

For the final design and in order to understand the vehicle-structure interaction, a combination of ADINA and NUCARS® modeling output was used to evaluate the performance of the track bridges and LRV as a system. (NUCARS is a registered trademark of Transportation Technology Center, Inc.) The ADINA model was used to simulate bridge response to LRVs passing across the fixed spans, track bridges, and transition span and then onto the floating span. Results from these analyses provided predictions of wing and rail stresses, and displacement input for the NUCARS® models, which were used to evaluate rider comfort and vehicle performance.

The bridge, including floating pontoon, anchor cables, piers, concrete slabs, rails, fasteners, FPBs and CESuRa track bridges were modeled in detail in ADINA using results obtained from an earlier study regarding pontoon behavior conducted by WSDOT in 2009.

A detailed model of the CESuRa track bridges was developed and inserted in the global model at the Interior and Exterior joints (Figure 7). Each CESuRa includes 34 friction pendulum bearings, which were modeled in detail using three-dimensional solid elements with the specific constraints included in the track bridge design.

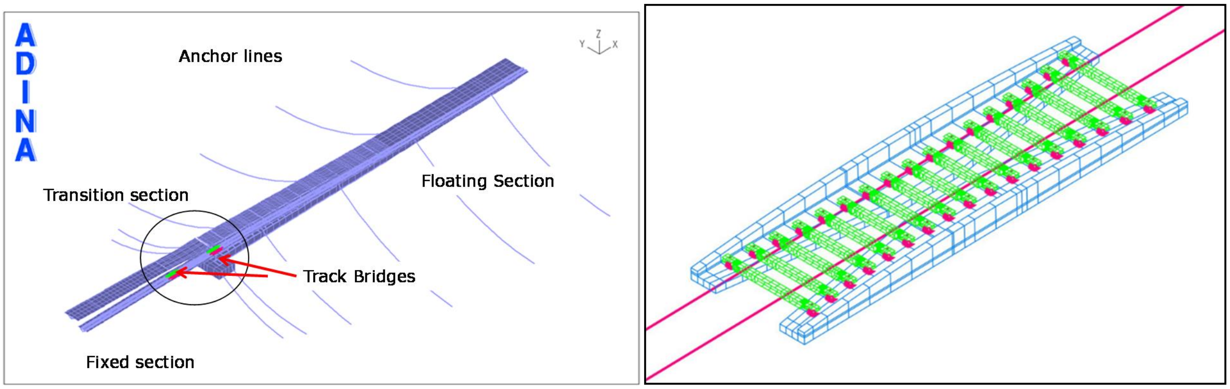


FIGURE 7 Isometric view of the ADINA FE model of the floating bridge and CESURA.

ADINA and NUCARS model comparison

To ensure the accuracy of the behaviors reported by these two models, an iterative convergence method was established. The deformations predicted from ADINA dynamic analysis with moving wheel loads were fed into the NUCARS® model, and the wheel-rail reaction force predictions from NUCARS® were returned to ADINA.

When a train crosses a track bridge, the rails move as a result of deflection and wing rotation. SC Solutions produced a 3-dimensional deflected rail "profile time history" (Dinitial) using preliminary wheel-rail force predictions from the ADINA model. Dinitial was then used as a dynamic input to the NUCARS® model as the LRV crossed the bridge. Time histories of vertical, lateral, and longitudinal forces between each wheel and rail were then output from NUCARS®. These "force time histories" (F2) were applied to the ADINA model of the bridge and a second three-dimensional profile time history developed (D2). While D2 results were fairly close to Dinitial, an additional iteration was made to close the loop (F3 and D3).

Correlation of results from the final design analysis and full-scale test model demonstrated that the track bridge system would meet all of the rider comfort criteria.

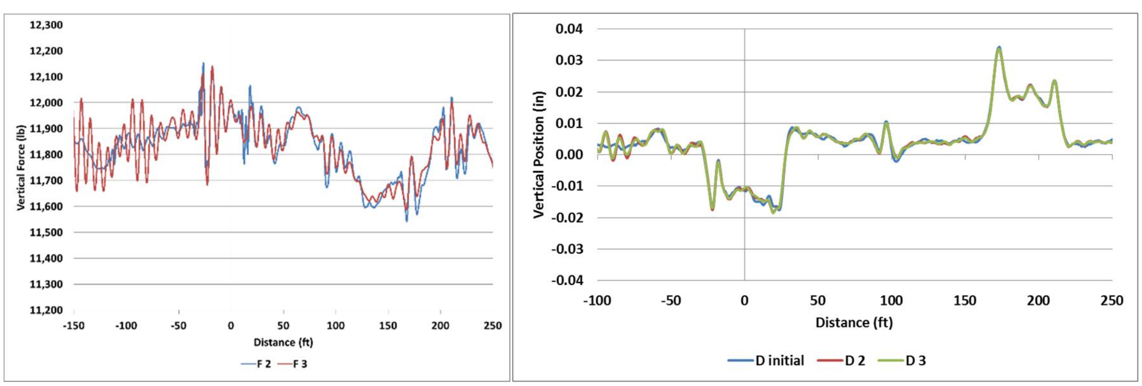


FIGURE 8 Vertical (left) and horizontal (right) forces for left wheel at axle 1.

Figure 9 shows predicted ride quality from NUCARS® using the D3 profile time history from ADINA. Vehicle performance was well within International Organization for Standardization ride quality criteria. (*15*) Results were also well within FRA safety criteria that were used for this project. Other simulations were conducted to evaluate the effects of traction and braking and forces and vehicle lateral stability. All results met criteria established by Sound Transit.

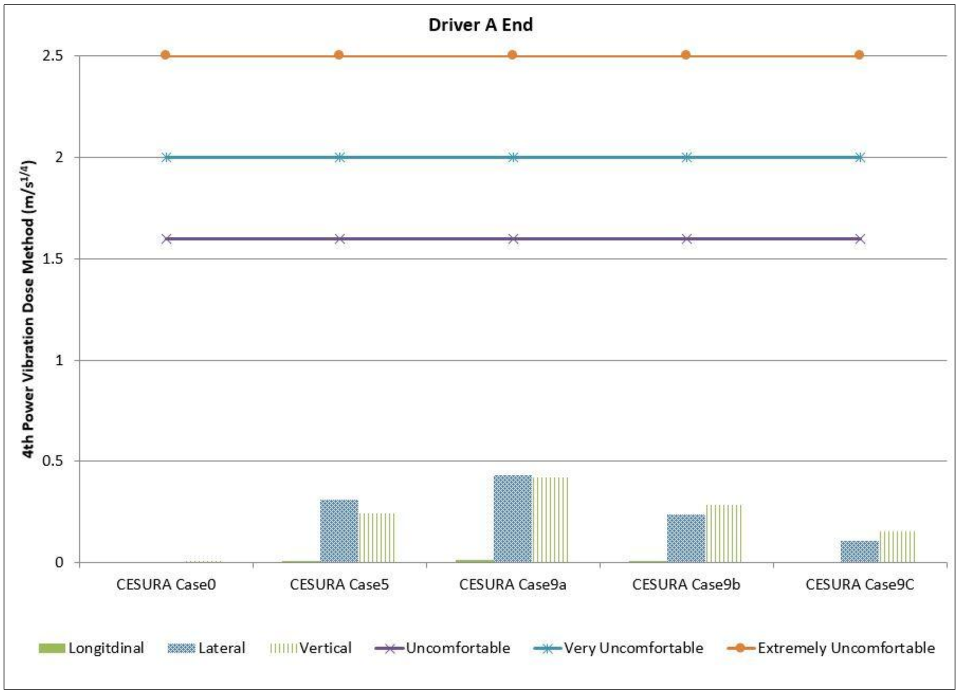


FIGURE 9 Track Bridge predicted ride quality from NUCARS.

Conclusion

The approach to modeling described above provided a good understanding of track bridge and vehicle interaction and proved to be a useful tool in the design process, providing valuable data to enhance the design for optimal structural and vehicle performance. Lessons were learned in the track bridge fabrication, test track construction, track bridge shipping and installation, and the multiple-testing phases of the program, all of which will benefit and improve the final fabrication, shipping, and installation of the eight production track bridges to be installed on the I-90 Bridge, most likely in 2019. After testing was completed in Pueblo, the two prototype track bridges were shipped back to Seattle in 2014, disassembled and stored so that the parts can be reused in the production of the final production units.

ACKNOWLEDGEMENT OF AUTHOR'S ROLES IN THE PROTOTYPE TESTING PROGRAM

John Harrison: PB Project Manager responsible for the design, construction, inspection and acceptance of the STTT, and observation of the Phase 3 and 4 testing and testing wrap-up; Tom Cooper: PB Design Manager. Prototype Track Bridge Engineer of Record and monitored all phases of the in-track testing; Lina Lawrence: PB Structural Engineer monitored all phases of the in-track testing, assisting with data analysis and report preparation; Bryan Williams: Jacobs Engineering; Civil/Track Design Lead, monitored completion of Phase 1 testing and track / OCS adjustments in preparation for Phase 2 testing; Charity Ketchum: TTCI Testing Manager responsible for test planning, all phases of in-track testing, data analysis and reporting; and John Sleavin: Sound Transit's Project Manager throughout the design and prototype testing program.

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