SOUND TRANSIT

HCT Planning

East Corridor HCT – Summary of I-90 Floating Bridge (Homer Hadley) Studies

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1. Introduction

This report summarizes previous studies conducted on the I-90 (Homer Hadley) floating bridge relating to potential future light rail transit operations, identifies major issues related to the design of a transition rail joint, and correlates these prior work efforts with the recent I-90 floating bridge tests conducted by WSDOT/ Sound Transit. It includes discussion of:

- The assumptions and assessments from prior rail joint studies, as well as design and operational elements to be considered in the design of a rail joint for the I-90 floating bridge structure;
- The operational assumptions for light rail vehicle type;
- Proposed track configurations;
- The associated bridge movements expected at the transition between the floating bridge and the transition structures; and
- Floating bridge mitigation measures to address light rail transit operations across the bridge.

2. I-90 Floating Bridge (Homer Hadley) Studies

Since 1985, multiple studies have been conducted to assess the feasibility of operating light rail on the I-90 floating bridge. These studies include an assessment of alternate loading scenarios, anticipated movement of the roadway structures, and consideration of the rail joint at the floating bridge and transition structure spans. A chronological summary of the key studies, as well as the documentation prepared as part of these studies, is presented in Attachment A.

2.1 I-90 Floating Bridge Analyses:

In 1985, design criteria for the new floating bridge were developed. The original WSDOT design considerations included design criteria for rail transit loading on the floating bridge.

Following the completion of the new I-90 Floating Bridge, the feasibility of running light rail transit on the newly constructed floating bridge was reassessed. Various track types and roadway configurations were studied to determine the effects on the floating bridge, including loss of freeboard and how to accommodate the movement of the expansion joint within the track design across the bridge. The technical memorandum prepared by Parsons Brinckerhoff/ Kaiser Engineering Team in 1991 *Use of I-90 Floating Bridge for Rail Transit Technical Memorandum Draft November 11, 1991* summarized this work, which indicated that there were no fatal flaws associated with incorporating LRT facilities on the I-90 Floating Bridge. The memorandum included a previously developed schematic of a design solution for the rail joint. This schematic rail joint is able to accommodate the required floating bridge movements included in the original design criteria.

In 2001 a KPFF report *Homer Hadley Interstate 90 Floating Bridge – Draft Structural Feasibility Study: Light Rail Conversion, September 2001* documented analytical studies of the movements of the floating bridge and at the expansion joints on the transition spans.

It was noted that trackwork, overhead contact system (OCS), maintenance walkway/cable tray and miscellaneous guideway elements increase the dead weight on the bridge and would reduce the existing freeboard. Alternate rail systems and rail positions were also investigated due to the sensitivity of the floating bridge to added weight (*KPFF Report, September 2001*). It was found that loss of freeboard is more sensitive to the rail system type than rail location. Because of this, the WSDOT analysis currently assumes continuous welded rail (CWR) with direct fixation track on doweled concrete single fastener plinth with restraining rail to reduce the dead load on the bridge.

The following bridge movements were identified in the 2001 KPFF report:

- Longitudinal Movement: +/- 2'-0.5"
- Horizontal Rotation: +/- 1.1 deg.
- Vertical Rotation: 2.2 degrees (downward)
- Loss of Freeboard due to Dead Load: approx 5 inches

Attachment A further details the studies and discussions carried out from 1985 to 2005.

2.2 I-90 Floating Bridge Test (2005)

In September 2005, the I-90 bridge tests were conducted to simulate LRT live loading, by driving flatbed trucks loaded with the approximate total gross weight of LRT vehicles across the I-90 bridge to simulate light rail operations. The actual movements of the bridge were measured using sensors placed in five locations on the west half of the bridge. Methodology and results of the study were included in the WSDOT report entitled *Homer Hadley Interstate 90 Floating Bridge Test Program for Light Rail Transit Draft Test Report November 14, 2005*.

The test results correlated with the movements predicted previously using analytical methods (as reported in 2001 by KPFF) and therefore verified that it was acceptable to use the developed analytical methods to study the response of the bridge to LRT live loading.

2.3 Comparison of I-90 Floating Bridge to Existing Comparable Rail Bridges

In a memorandum to Sound Transit from Puget Sound Transit Consultants (PSTC) dated October 4, 2001, PSTC identified examples of modern rail bridges that have rail joints designed to accommodate similar movements to those expected for the I-90 floating bridge. The two bridges were: Tagus River Suspension Bridge (Lisbon, Portugal) and the SkyTrain Cable Stayed Bridge (Skybridge) across the Fraser River (Vancouver, B.C., Canada), both of which have a successful history of passenger rail operation.

Table 1 below provides a comparison of these bridges by movement type: longitudinal movement, horizontal rotation and vertical rotation. Movements on the Tagus River Suspension Bridge (Lisbon, Portugal) exceed those expected on the I-90 floating bridge and movements on the SkyTrain Cable Stayed Bridge (Vancouver, B.C., Canada) are slightly less than those expected on the floating bridge.

Horizontal rotation was not specified for the Tagus River Bridge or Skybridge; however changes in horizontal rotation due to temperature or live loading translates into additional longitudinal movement and slight horizontal rotation of the rail. It is expected that even though the horizontal rotation is not specified for either joint, they actually accommodate horizontal rotation similar to those that would occur on the I-90 Floating Bridge.

The October 2001 memorandum from PSTC reported that rail joints developed by others for both the Tagus River Suspension Bridge and SkyTrain Cable Stayed Bridge are currently operating for movements of similar magnitudes to those anticipated for the I-90 floating bridge. The memo concluded that a joint design for the I-90 Floating Bridge could be developed.

Table 1 Summary of Bridge Movements Identified in Previous Studies

Movement	**I-90 Bridge (modeled)[1]**	**Tagus River Bridge (Lisbon Portugal)[2]**	**Skybridge (Vancouver Canada)[2]**
Longitudinal Movement (Includes extra movement required for horizontal rotation)	+/- 2'-0.5"	+/- 5'-0"	+/- 1'-1.1"
Horizontal Rotation (Rotation of transition span due to its transverse displacement at floating bridge)	+/- 1.1 deg.	Not specified[3]	Not specified[4]
Vertical Rotation (Rotation of transition span due to its vertical displacement at floating bridge)	2.2 degrees (downward)	+/- 3.43 deg	+/- 0.75 deg

[1] Fax from KPFF to PSTC March 16, 2001
[2] Memorandum from PSTC to Sound Transit October 4, 2001
[3] The AREMA technical paper *Design of Continuous Welded Rail on a Suspension Bridge, 2000, Ranganatha R,Rao and Sudhir Sanghvi* does not specifically mention provision for horizontal deflection and the angular change at the joint between the anchorage and the 323.5 foot backstay spans which would be caused by transverse horizontal loads such as wind or seismic. It is possible that a similar joint assembly would be able to accommodate the 1.1 degree floating bridge joint requirement with appropriate modification (see Memorandum from PSTC to Sound Transit October 4, 2001)
[4] The memorandum from PSTC to Sound Transit October 4, 2001 states "based on the bearing and joint design criteria. The criteria specified 0.20" (5mm) gap between bearing guidebars."

Skybridge (Vancouver, B.C., Canada)

Due to temperature, wind and live load, the Skybridge rail joint undergoes vertical and horizontal angular changes and longitudinal movement. The Skybridge rail joint consists of two parts:

1. A 13ft to 14.5ft (4m to 5m) long section of track on the fixed section of the bridge transition structure, consisting of the sliding rail joint which allows for a longitudinal movement of the rail (refer Figure 1 and Figure 3 below). The sliding rail joint consists

of two separate rails, one rail that is a standard shape and slides along the side of the adjoining rail, the adjoining rail tapers to a point and is fixed. The tapered fixed rail enables a smooth transition for the train wheel across the joint accommodating longitudinal movement in the rail. This joint also accommodates horizontal rotation that results in longitudinal movement.

2. A 13ft to 14.5ft section straddling the bridge expansion joint, consisting of ten tie plates, each with two spring devices that enable the rail joint to undergo vertical angular change (refer Figure 1 and Figure 2 below).

Figure 1. Diagrammatic Representation of the Skybridge Rail Joint Movements

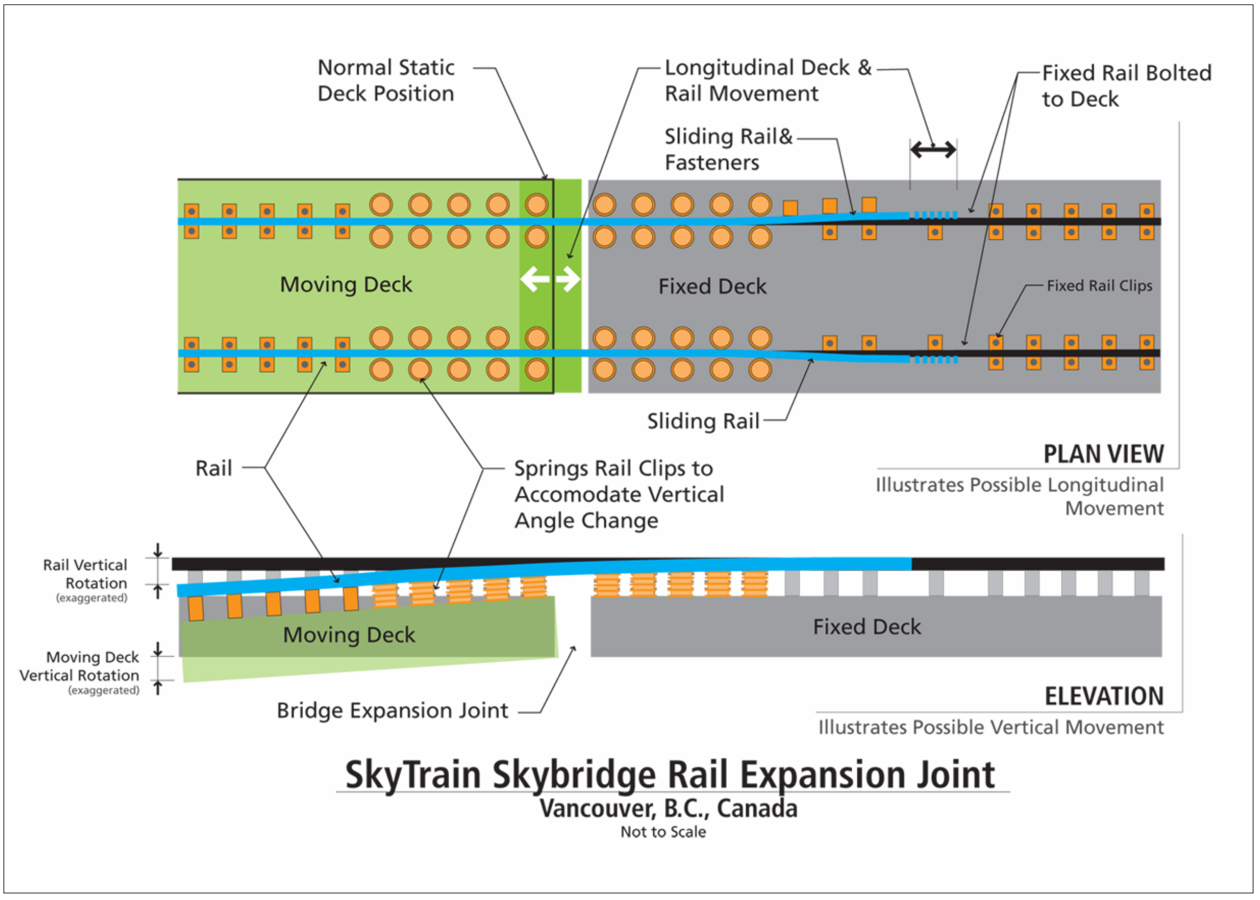


Figure 2. Vertical Adjustment Section of the Skybridge Expansion Joint

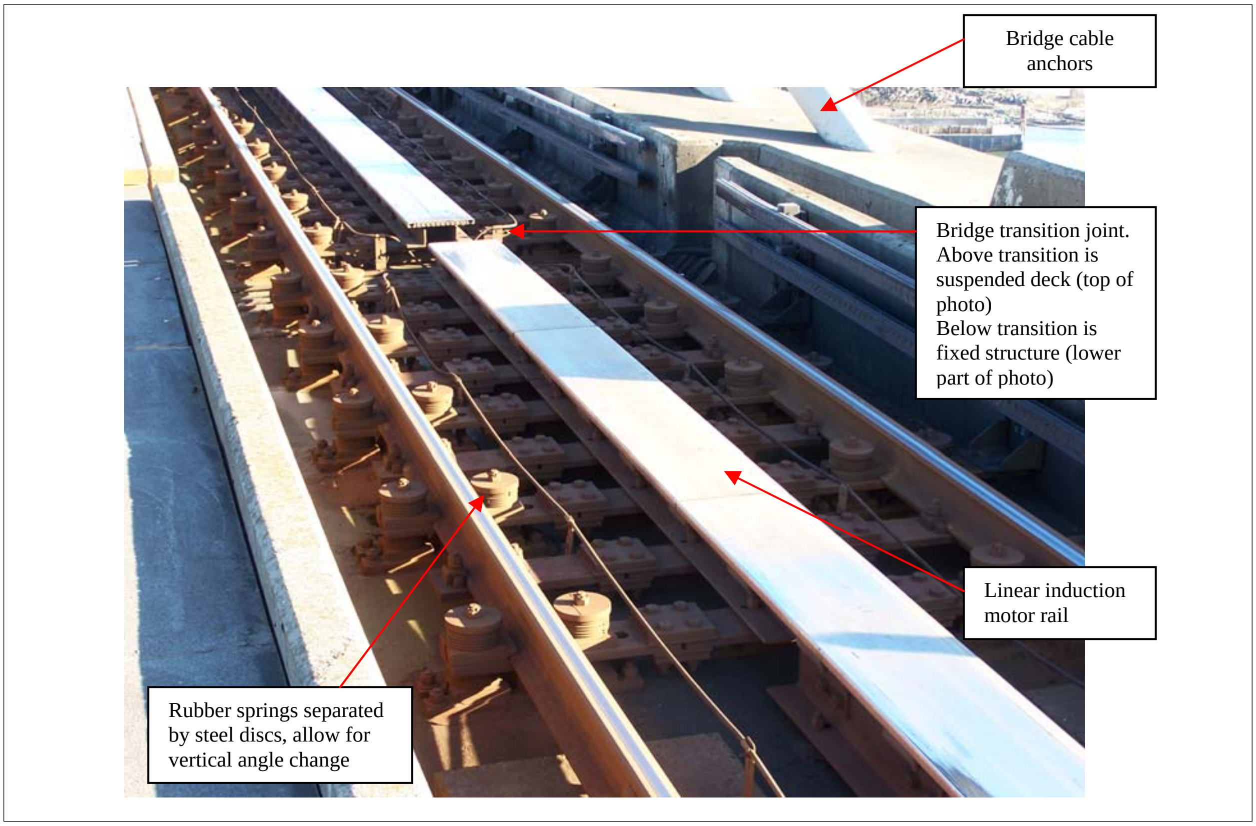
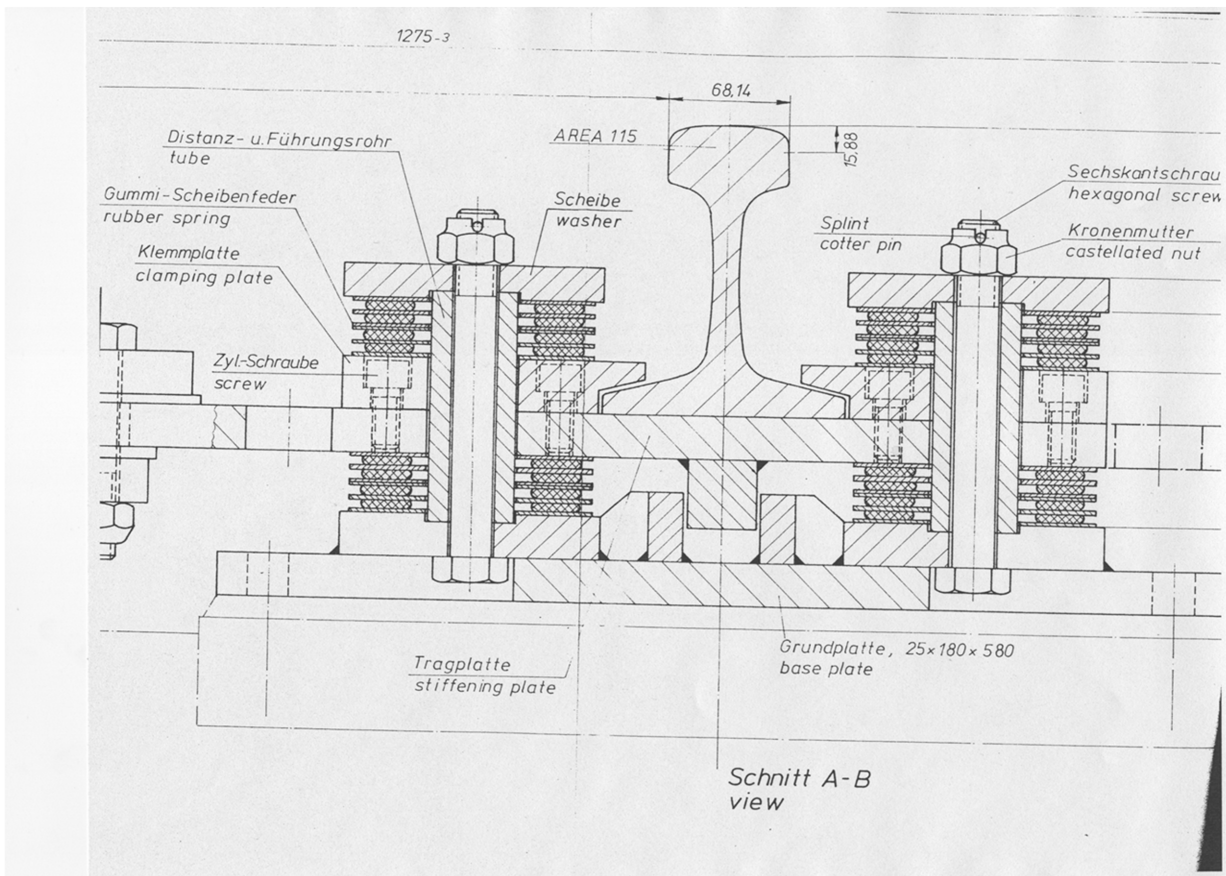


Figure 3. Fixed Side of the Rail Expansion Joint (matches to bottom of Figure 1)

Figure 2 identifies rubber springs that are separated by steel discs attached to each of the tie plates. Over the joint there are 10 tie plates each with two spring devices. Figure 4 below details the rubber spring and rail configuration. Underneath each base or tie plate, different types of polyurethane grout have been injected. This grout changes volume under compression and helps facilitate a smooth transition for the rail over the expansion joint as the bridge moves vertically. The rail moves longitudinally as well between the two spring systems.

Figure 4. Extract from Skybridge drawings detailing the Rubber Spring and Rail Configuration



The total length of the rail joint is 39 ft (11.9m). SkyTrain staff confirmed that the Skybridge rail joint has been in operation for approximately 16 years and no adverse operation or maintenance issues have been encountered for the rail joint over this period of time.

Attachment B contains additional photos of the rail joint on Skybridge, the cable stayed SkyTrain Bridge across the Fraser River (Vancouver, B.C.).

Tagus River Bridge (Lisbon, Portugal)

Attachment C contains the AREMA technical paper *Design of Continuous Welded Rail on a Suspension Bridge, 2000, Ranganatha R. Rao and Sudhir Sanghvi.* The following is a brief summary explanation of the Tagus River Bridge rail and expansion joint configurations as discussed in the attached technical paper. Key points and some direct text from the paper has been used in the following summary of *Design of Continuous Welded Rail on a Suspension Bridge, 2000, Ranganatha R. Rao and Sudhir Sanghvi.*

The Tagus River suspension bridge in Lisbon, Portugal was originally built to carry four lanes of traffic on the upper deck level with design provision for a second phase construction to allow for future railroad track installation at the bottom cord of the truss below. The bridge has since been retrofitted to add two railroad tracks at the lower level and widen the upper deck to accommodate six lanes of traffic.

The expansion assembly consists of moving telescopic girders mounted on vertical rollers and restrained by horizontal rollers between the stationary girders. Longitudinally split track rails are mounted on these girders. Split rails are L-shaped rails and are illustrated in Figure 12 Section C of Attachment C. The tip of the rail facing the direction of rail traffic is specially shaped to transfer the rolling wheel smoothly to the adjacent split rail (this is similar to the slip rail joint described above for the Vancouver Skybridge).

Across the bridge the track layout is divided into different zones (refer to Attachment C, Figure 3 which illustrates each of the rail track zones):

- Standard zone (also the rail slip zone)
- Anchor zone
- End zone
- Expansion zone
- Creep free zone

The standard zone consists of continuous welded rail. The track in this zone deflects as required to suit the suspended truss. The anchor zone is at the end of the bridge and is where the continuous welded rail terminates and is anchored through an anchor joint where the rail is rigidly connected in the longitudinal direction. The end zone is the short section of track between the anchor joint and the expansion joint structure. The expansion zone contains the expansion assembly structure. Following this is the creep free zone which protects the expansion structures and stops any longitudinal movements.

The thermal expansion of the truss is significant and the truss ends move in and out due to the deflection of the truss under live load. If the running rail is rigidly fixed this would result in a kink in the rail and high bending and fatigue stress, therefore the rail is mounted such to allow for the rail base to adjust to the imposed curvature of the truss. To deal with the required movements of the running rail, a unique expansion assembly structure was developed for the Tagus River Bridge.

The expansion joint has two functions; longitudinal movement and dispersion of angular bend. The expansion structure consists of the following components (refer to Attachment C, Figures 9, 10, 11 and 12 which illustrate each of the joint components):

- Transition girder and telescopic girders
- Split rails for rail expansion
- Check rail and its expansion arrangements
- Angular bend dispersion components

- Telescopic girder mountings

The transition girder is inserted between two stationary telescopic girders and held laterally and rigidly by two horizontal rollers. The split rails are mounted on the stationary and moving girders back to back. The check rail expansion is continuous over the expansion gap and is extended from the truss over the telescopic girder and expansion joint up to the approaches to provide lateral restraint to the wheel.

Double track and expansion joint units were successfully installed and open to rail on the Tagus River Bridge in July, 1999.

3. Future Design Considerations for Rail Joint and LRT Operations

The following are design considerations that should be considered during design of the I-90 floating bridge for LRT operation. These design considerations are based on Link Light Rail Design Criteria, the KPFF reports *Homer Hadley (Interstate 90) Floating Bridge – Draft Structural Feasibility Study Light Rail Conversion September, 2001*, and *Homer Hadley Interstate 90 Floating Bridge Test Program for Light Rail Transit Draft Test Report November 14, 2005.*

Design Criteria:

- For vehicle load requirements adopt the LRT design vehicle load as per Fig. 8.1 of the Link Light Rail Design Criteria.
- Dead loads for single-fastener plinth design with restraining rails to be taken from KPFF September, 2001 report (see Attachment A).
- It should be noted that design of the I-90 floating bridge considered HS20 loading which is a lighter design load then the current standard HS25 loading. As part of the WSDOT test program (see *Homer Hadley Interstate 90 Floating Bridge Test Program for Light Rail Transit Draft Test Report November 14, 2005*) WSDOT concluded that the strength and serviceability criteria for pontoon global response are met at mid-span and at the far west end of the bridge for live loading due to two tracks of Sound Transit's LRT system in combination with HS25 traffic on the westbound roadway. WSDOT also concluded that a comprehensive analysis of all remaining pontoons of the bridge should be done during final design.
- Adopt WSDOT criteria to keep bridge in trim and maintain zero net freeboard loss after addition of rail system components.
- The light rail vehicle location on the I-90 Floating Bridge is to be as per LR(mod) rail system at track location 3 as detailed in the KPFF September, 2001 report (LR(mod) at location 3 represents the terminology used to represent the rail system designation and the location as detailed in the September, 2001 report).

Mitigation measures required to maintain zero net freeboard loss:

(As per KPFF September, 2001 and November, 2005 reports and the WSDOT December 15, 2005 *Board Briefing on the I-90 Bridge Studies*)

- Removal of existing south concrete barrier and replacement with cable railing.
- Removal of auxiliary ballast within the floating bridge pontoon cells.

- Removal of one inch of the existing concrete overlay on the south side of the concrete median barrier and replacement with ¼ inch of polymer concrete overlay.
- Remove auxiliary ballast.
- Limit location of rail on bridge deck; accommodates fourth westbound traffic lane.
- Addition of buoyancy is not included in mitigation.

Additional Design and Operational Considerations:

- Fatigue in the rail fastening systems, resulting from differential deflection between the bridge structure and rail, may require use of rigid clips and fastenings at the joint.
- Rail Convertible Bus Rapid Transit (RC BRT) and LRT operation scenarios are currently under considerations along the I-90 corridor.
- Joint (dual) operation of LRT vehicles and buses on I-90 structure is not contemplated in the center roadway.

4. Summary

The live load test carried out by WSDOT in 2005 (*Homer Hadley (Interstate 90) Floating Bridge Test Program for Light Rail Transit Draft Test Report November 14, 2005)* validated the previous 2001 WSDOT computer model results (*Homer Hadley (Interstate 90) Floating Bridge – Draft Structural Feasibility Study Light Rail Conversion September 2001*). Based on this analysis, WSDOT concluded that it is feasible for the I-90 Floating Bridge approach and transition structures to support the increased loading for LRT. A reduction in dead weight is required in order to mitigate freeboard loss due to light rail loading. The WSDOT studies also provide information about the anticipated movements of the I-90 bridge with light rail. Comparison of the anticipated movements on the I-90 bridge relative to movements of other existing, modern rail bridges demonstrate that it is feasible to design a rail joint to accommodate the movements of the I-90 Floating Bridge across the existing joints. Design of the joint will be developed in project level analysis if light rail is selected as the preferred mode for the East Corridor HCT alignment.