Track Bridge System & Prototype Project
Phase 1 Design Services Technical Requirements
Track Bridge Workshop Summary Report

Prepared for:
Sound Transit

Prepared by:
Sound Transit East Link Project Team

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Quality Tracking

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SOUND TRANSIT EAST LINK PROJECT

APPENDIX B

TRACK BRIDGE SYSTEM & PROTOTYPE PROJECT PHASE 1 DESIGN SERVICES

Track Bridge System Technical Requirements

07 September, 2010

SOUNDTRANSIT

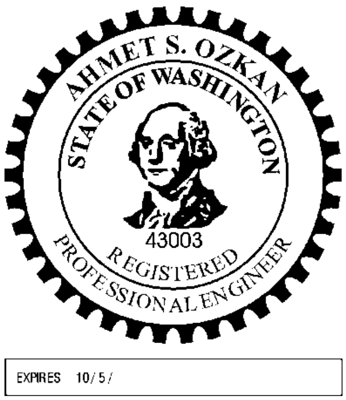
CENTRAL PUGET SOUND REGIONAL TRANSIT AUTHORITY

Translation services and information in accessible formats are available upon request by calling 1.800.201.4900 (voice) or 206.398.5410 (TTY).

For more information about the Track Bridge System and Prototype Project Phase 1 Design Services Technical Requirements call John Oreiro at (206) 689-3334 or write Sound Transit, 401 South Jackson Street, Seattle, WA 98104-2826. You may also e-mail John Oreiro at john.oreiro@soundtransit.org.

CERTIFICATE OF ENGINEER

The work contained herein was prepared under the supervision and direction of the undersigned.



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TRACK BRIDGE SYSTEM & PROTOTYPE PROJECT

PHASE 1 DESIGN SERVICES

Track Bridge System Technical Requirements

Table of Contents

Technical Requirements

I. GENERAL INFORMATION

Puget Sound region's transit agency, Sound Transit (ST), is planning to install light rail transit (LRT) tracks on the I-90 Homer Hadley floating bridge as part of the East Link project. The I-90 Homer Hadley floating bridge is a critical component of the Puget Sound region's transportation infrastructure and carries one of two highways that span Lake Washington to link Seattle with the Eastside and beyond. Given the importance of the existing floating bridge and the innovation required to place Light Rail over this structure, the development and testing of a full scale Track Bridge prototype is required to allow the validation of the design solution prior to its installation on the I-90 structure.

The placement of Light Rail across the floating bridge presents unique challenges, including multidirectional movement at the existing expansion joints that accommodate the changes in the bridge position due to changing bridge elevations, vehicle traffic loading, wind, waves and, for extreme conditions, severed anchor cables. When combined with the dynamic response of the light rail train, this results in multiple geometric positions of the bridge within a specific range of motion. The solution must provide a low maintenance, reliable and acceptable track structure onto the main span of the floating bridge.

Definitions:

Track Bridge: Trackway multidimensional movement joint supporting the tracks, the connections to the existing bridge and the track rails across the trackway joint. There are eight (8) Track Brides required, two (2) each at piers 7, 9, A-1 and R-1.

Expansion Joints – Existing joints are located at the ends of the transition spans (at Pier 7, Pier A-1, Pier R-1 and Pier 9 of Bridge 090/025N, LM Line) and allow for the bridge's movement via special modular joint systems, designed for rubber tired vehicles.

Transition Spans – Transition spans are simple supported structural steel box girder bridges. West Transition span length is 192 feet between Piers 7 and A-1, whereas East Transition span is 202 feet between Piers R-1 and 9.

Track Bridge System – Along the transition spans the LRV will traverse approximately 200 feet between two Track Bridges. Along the continuous profile of each track across the two Track Bridges, from fixed approach, along the transition span and onto the floating span, the choice of various track components such as running and restraining rails, slip joints, fasteners, attachments, etc., may require special design. The "Track Bridge System" is defined as the sum of all the components that are required to successfully operate LRT, including the Track Bridge structures and trackwork, and their attachment to the existing bridge, monitoring and controls of the Track Bridge System, and all design interfaces for stray current control, traction power, signals and communications. The limits for the Track Bridge System, beyond the existing floating bridge expansion joints, will be determined by the Phase 1 design.

Across the floating bridge, there are four (4) Track Bridge Systems required; two each at the west end and two each at the east end of the floating bridge. The Consultant shall confirm a single design will accommodate all four Track Bridge Systems. Each Track Bridge System requires two (2) Track Bridges.

Track Bridge Prototype - A full-size fabricated model of the proposed Track Bridge at the Interior Joints of the floating bridge (piers A-1 and R-1) including the rail expansion joint, to be tested in accordance with the design criteria.

Project Description

The project, composed of two phases, includes the design, fabrication, and testing of a prototype Track Bridge, including the approach trackwork. The Project consists of the following components:

PHASE I

- Design a Track Bridge System;
- Design the testing program;
- Design the testing facility;
- Design the test vehicle; and
- Design the monitoring and controls instrumentation for the prototype testing and for the operation Track Bridge.

PHASE II

- Furnish a site for prototype testing;
- Fabricate the Track Bridge;
- Test the Track Bridge Prototype based on acceptance criteria;
- Modify the design and prototype and re-test as needed to obtain final acceptance from Sound Transit;
- Prepare final construction plans for the Track Bridge System; and
- Finalize an Operating Plan and Inspection & Maintenance Manual.

II. DESIGN CRITERIA

Units of Measurement

The Project shall be designed, constructed, and documented in the English units of measure.

Standards

The current editions of the following list of publications shall apply to all design and construction. They are listed in the order of precedence. This is not a comprehensive list; other applicable publications may be required to complete the design and construction. If the TBDC becomes aware of any ambiguities or conflicts relating in any way to these Standards, the TBDC shall notify Sound Transit immediately for resolution.

- Sound Transit East Link Design Criteria Manual (DCM)
- Track Bridge Prototype Project Technical Requirements
- WSDOT Construction Manual (M 41-01)
- AASHTO LRFD Bridge Construction Specifications
- WSDOT Materials Manual (M 46-01)
- WSDOT Qualified Products List (M 46-02) (QPL)
- CFR Title 49 Part 213 Track Safety Standards
- UIC 774-3R Track-Bridge Interaction, Recommendations for Calculations
- UIC 776-2R Design Requirements for Rail Bridges based on Interaction Phenomena between Train, Track and Bridge
- CFR Title 46 Part 170 Stability Requirements for all Inspected Vessels
- CFR Title 46 Part 174 Special Rules Pertaining to Specific Vessel Types
- Report of the Governor's Blue Ribbon Panel investigation into the sinking of the I-90 Lacey V. Murrow Bridge," dated May 02, 1991.

The TBDC shall obtain Sound Transit's prior approval for any proposed deviations from the above criteria.

Track Bridge System/Floating Bridge Interaction

A floating bridge takes advantage of buoyancy to support dead, live and environmental loads on a structure. There is no need for conventional piers or foundations. However, an anchoring system is needed to maintain transverse and longitudinal alignment of the bridge. A floating bridge is basically a beam on an elastic foundation and supports. Vertical loads are resisted by buoyancy. Transverse and longitudinal loads are resisted by a system of mooring lines or anchor cables. Placing light rail on a floating bridge and its fixed approaches is a unique challenge since the floating bridge is not stationary. Environmental factors such as wind and waves or changes in the lake's water level result in vertical and horizontal alignment changes, which in turn affect the riding characteristics of the moving

trains and the stresses imposed on the tracks and support structure. Movements in the floating bridge occur due to shrinkage and creep, and temperature changes, as well as the environmental factors noted above.

When combined, these factors on a floating bridge result in much larger magnitudes of movement than from a normal bridge structure. The design criteria for the Floating Bridge transition structures were classified by WSDOT in two categories: service requirements and extreme conditions. Service Conditions are those conditions that occur regularly and would be typical of the operations on the bridge and LRT track way on an annual basis. The extreme conditions occur rarely, corresponding to catastrophic event or extreme weather condition.

Weight Mitigation

The cross pontoons A and R at the ends of the floating span weigh 18,229 kips each, including all the installed features and reserve ballast. The Track Bridge System additional weight and associated freeboard loss shall be mitigated to maintain a minimum freeboard of 7′-0″. Allowable additional weight on the cross pontoons depends on the amount of the reserve ballast. Pontoon A's SW cells has 260 kips reserve ballast whereas Pontoon R's SE cells has 210 kips reserve ballast. **Therefore, the total maximum Track Bridge System weight shall be limited to 200 kips per cross pontoon.**

The draft (hence the freeboard) of the bridge is an important parameter not only for bridge operations and safety, but also maintenance considerations, such as anchor cable replacement, and for the watertight integrity of the anchor galleries. **The pontoons shall provide a minimum freeboard of 7′-0″. The freeboard shall be calculated based on the following criteria:**

- The floating bridge is to remain in trim following the implementation of the proposed light rail system and any Track Bridge System design alternative. This implies that should any weight change occur which causes the bridge to list, appropriate trim ballast shall be added to compensate for the out of balance condition to "re-level" the bridge.

Hydrostatic analysis shall be performed on the floating bridge to determine the loss of bridge freeboard (height above waterline) due to proposed system configuration. Freeboard loss shall be based on the new track dead load and corresponding ballast required to trim the bridge back to a level condition.

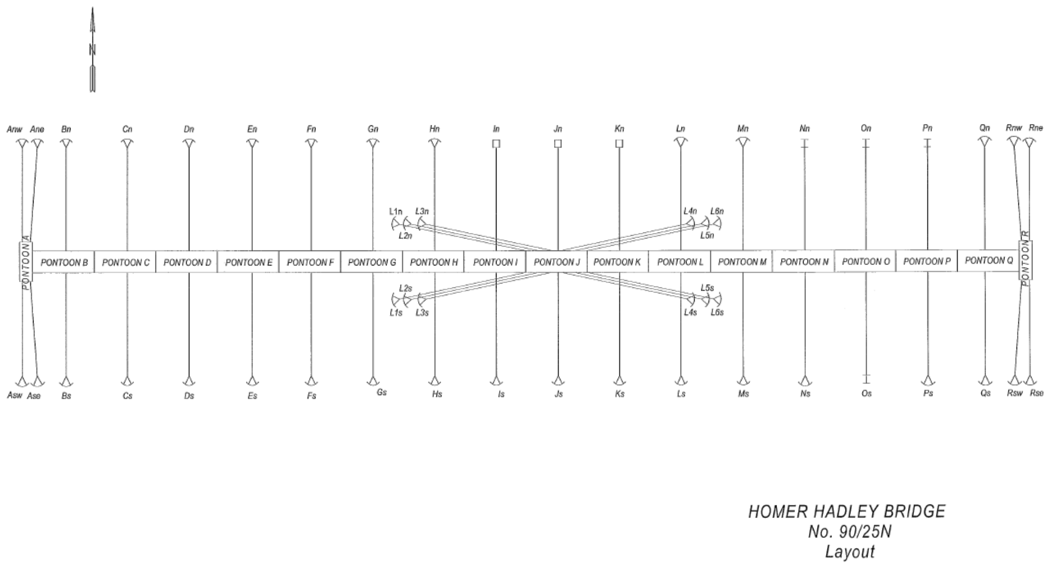


EXHIBIT 1
Homer Hadley Bridge Pontoon Layout

Movement Parameters for Design

The expected movements for different load conditions as well as maximum design joint movements that occur at the expansion joints located between the fixed and floating spans of the bridge, at Pontoon Piers A-1 and R-1, are shown in Table 1 and the definition of the movements are shown in Exhibits 2, 3 and 4. The joints at the Pontoon Piers A-1 and R-1 are identified as "Interior Joints (IJ)".

TABLE 1
Movements (Interior Joint, IJ, at Pontoon Pier A-1; Pier R-1 is similar)

Movements due to	**Surge (inch)**	**Heave (inch)**	**Sway (inch)**	**Roll (degree)**	**Yaw (degree)**	**Pitch (degree)**
Service Conditions						
Lake Level Change	-0.48 > X > +0.53	+9.6 > Y > -12.0	0	0	0	-0.25 > θv > +0.31
Temperature Change	-2.2 > X > +2.2	0	0	0	0	0
Highway Loading	-0.11 > X > +0.11	-2.0 > Y > 0	-5.5 > Z > 0	-0.6 > θr > +0.6	-0.01 > θh > +0.01	-0.08 > θv > +0.08
Wind and Waves	0	+0.8 > Y > -0.8	-1.3 > Z > +1.3	-0.05 > θr > +0.05	-0.03 > θh > +0.03	-0.04 > θv > +0.04
Extreme Condition						
Extreme Event	-24.5 > X > +24.5	+9.6 > Y > -45.6	-36.0 > Z > +36.0	-2.0 > θr > +2.0	-1.1 > θh > +1.1	-0.3 > θv > +2.2

Similar design joint movements that occur at the expansion joints located between the fixed and floating spans of the bridge, at Fixed Piers 7 and 9, are shown in Table 2 and definition of the movements are shown in Exhibits 2 and 3. Those joints at the Fixed Piers 7 and 9 are identified as "Exterior Joints (EJ)".

TABLE 2
Movements (Exterior Joint, EJ, at Approach Span Pier 7; Pier 9 is similar)

Movements due to	**Surge (inch)**	**Heave (inch)**	**Sway (inch)**	**Roll (degree)**	**Yaw (degree)**	**Pitch (degree)**
Service Conditions						
Lake Level Change	-0.48 > X > +0.53	0	0	0	0	-0.25 > θv > +0.31
Temperature Change	-2.2 > X > +2.2	0	0	0	0	0
Highway Loading	-0.11 > X > +0.11	0	0	0	-0.01 > θh > +0.01	-0.08 > θv > +0.08
Wind and Waves	0	0	0	0	-0.03 > θh > +0.03	-0.04 > θv > +0.04
Extreme Condition						
Extreme Event	-9.0 > X > +9.0	0	0	0	-1.1 > θh > +1.1	-0.3 > θv > +2.2

These movements are provided as guidance to the TBDC for calculating service condition movements and they exclude any influence from the LRT vehicle. The design movements shall include the movements caused by the LRT vehicle load combinations over the Track Bridge System, to be determined by the TBDC.

Notes for movements listed in Tables 1 and 2:

1. Movements are relative to a fixed point.
2. Values are provided at Pontoon Pier A-1 and Fixed Pier 7. Values at Pontoon Pier R-1 and Fixed Pier 9 are equal or less than provided numbers.
3. LRT vehicle movements are not listed and shall be calculated by TBDC. The *Homer Hadley (Interstate 90) Floating Bridge Test Program for Light Rail Transit*, Test Report will be provided as a reference.
4. Temperature movements are based on 10 degree F temperature differential.
5. Highway Loading movements are based on HL-93 loads along LL Line only, with a multiple presence factor of 0.65.
6. Wind and Wave movements are based on Glosten's 1983 Report.
7. Lake level and anchor cable tension affect the amount of floating structure movement. Cable tensions are seasonally adjusted by WSDOT to maintain

standard forces. Table 1 and 2 movement values assume cable tension is maintained.

EXHIBIT 2
Elevation Sketch at Transition Span Showing Longitudinal Translation and Vertical Rotation Movement

EXHIBIT 3
Plan Sketch at Transition Span Showing Horizontal Rotation Movement

Multidirectional Movement Capability

The Track Bridge System, which includes the LRT rails, shall be designed to accommodate floating bridge pontoon movements in all six directions. These six movements are shown in Exhibit-4 and specified below:

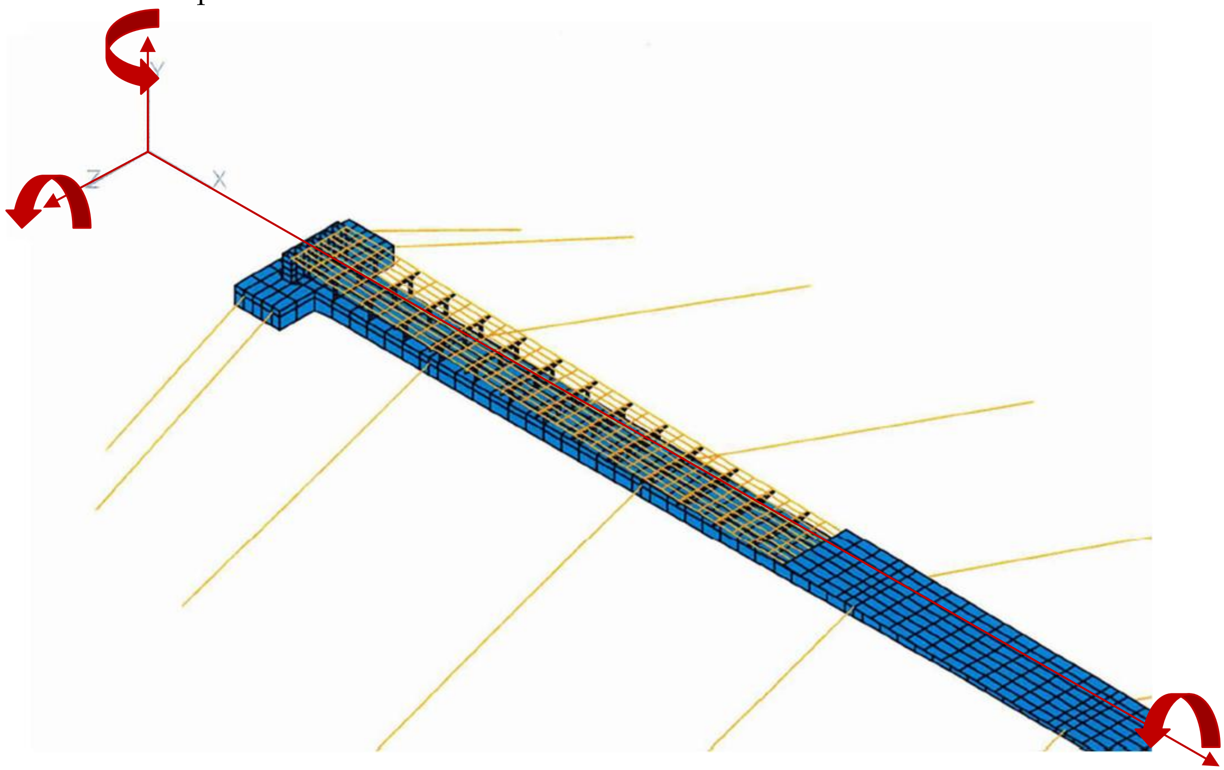


EXHIBIT 4
FEM Rendering of Floating Bridge (West End) Showing Movement Directions

Surge - The longitudinal x-axis passes through the pontoon from nose to tail. Translation along this axis is called "Surge".

Heave - The vertical y-axis passes through the pontoon from top to bottom. Translation along this axis is called "Heave".

Sway - The lateral z-axis passes through the pontoon from side to side. Translation along this axis is called "Sway".

Roll - The longitudinal x-axis passes through the pontoon from nose to tail. Rotation about this axis is called "Roll.

Yaw - The vertical y-axis passes through the pontoon from top to bottom. Rotation about this axis is called "Yaw".

Pitch - The lateral z-axis passes through the pontoon from side to side. Rotation about this axis is called "Pitch".

Under normal operating conditions (Service Conditions) the movements are much smaller than extreme event values specified in Tables 1 and 2. To verify the operational speed of the light rail vehicle (LRV) under normal conditions (service conditions) the movements provided in Tables 1 and 2 shall be combined by using load combinations as listed in Table 3.

Loads

Loads for design of the Track Bridge System and floating bridge shall be as specified in the Sound Transit DCM except as modified below.

Change in Lake Level (K)
A rise of 0.8 feet and a drop of 3.8 feet (as controlled by the operation of the locks) in Lake Washington water levels shall be considered in the design.

Ballast (BT)

Change in loads resulting from temporary or permanent ballast removal shall be considered in the design. Gravel ballast shall be assumed to have a unit weight of 109 pcf.

Wind and Wave on Structure (WS and SW)

WS-1 = wind load – 1 year storm

WS-100 = wind load – 100 year storm

SW-1 = wave load – 1 year storm

SW-100 = wave load – 100 year storm

Wind and wave loads include steady state and dynamic loading as developed by the Naval Architect Consultant. The movements resulting from wind and wave motion responses are listed in “Wave Loading Analysis of Lake Washington Bridges, Volume II, Analysis and Results, New I-90 Floating Bridge”, by The Glosten Associates Inc., May 1983.

Potential Damage (DM)

The Track Bridge System shall have sufficient capacity to remain elastic through the extreme condition and provide a track geometry supporting the design speed required. Damage could result from vessel collision, flooding, or severing of anchor cables. Consider only one damage condition and location at any one time.

Load Combinations

Service condition load combinations and load factors for design of the Track Bridge System and floating bridge shall be as specified in the Sound Transit DCM except as modified below as shown in Table 3.

TABLE 3
Service Level Design Load Combination

Load Combination Limit State	**Description of Limit State**	**B E DL PS S BT**	**CF IV IH LF LL**	**SF K**	**W WS-1 SW-1**	**WL**	**T**	**DS**
Service Condition	**Multidirectional Movement**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	γ_T	γ_{DS}

Extreme Event load combinations and load factors for design of the Track Bridge System and floating bridge for the structural components shall be as specified in the Sound Transit DCM except as modified below as shown in Table 4.

TABLE 4
Extreme Event Design Load Combination

Load Combination Limit State	Description of Limit State	B E DL PS S BT	CF IV IH LF LL	SF K	W WS-100 SW-100	WL	T	DS	DM
Extreme Event	**Cable Break**	γ_p	**1.00**	**1.00**	**1.00**	**1.00**	__	__	**1.00**
Serviceability	**Fatigue & Fracture**	__	**0.75**	**1.00**	__	__	__	__	__

Running Speed

Light rail vehicle design speed over the Track Bridge System is determined by geometry and rider comfort constraints. The LRV design speeds are as listed in Table 5, and shall be verified by the TBDC from actual design development.

TABLE 5
Load Cases versus Minimum LRV Speeds over the Track Bridge System

	LOADING				
CASE	**LIVE LOAD**	**LAKE LEVEL**	**STORM**	**POTENTIAL DAMAGE**	**DESIGN SPEED**
SERVICE	YES	0.8 FT RISE 1.0 FT FALL	1 YEAR RP	NO	55 MPH
EXTREME	YES	0.8 FT RISE 3.8 FT FALL	100 YEAR RP	TWO ANCHOR CABLES BROKEN	10 MPH

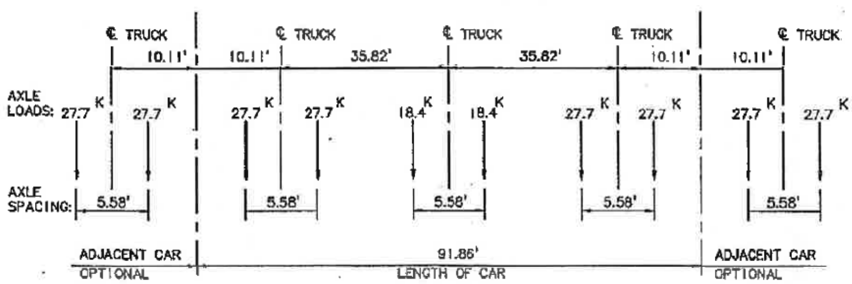
Rider Comfort

As the LRV crosses the Track Bridge System, the path of the wheels follows the rails, which will be deformed by expansion joint rotation, due to the response of the bridge and water. This "plunging" effect causes acceleration loads on the vehicle and passengers. These accelerations must meet guidelines for passenger comfort. The maximum acceptable single amplitude acceleration is 0.05 g.

Vehicle Considerations

Data regarding the Sound Transit light rail vehicle are provided in Appendix B. Design of the Track Bridge System, which includes the attached rails for LRT, shall accommodate the following light rail vehicle considerations: underbody clearance; suspension; and truck spacings and axle loads, keeping in mind that multiple-vehicle train consists will typically run during revenue operations. Exhibit 5 below is the light rail vehicle loading diagram from the Sound Transit Design Criteria Manual.

Light Rail Vehicle Design Load



LIGHT RAIL VEHICLE LOADING

Notes:

1. AXLE LOAD IN KIPS.
2. THE TRAINS SHALL CONSIST OF ONE, TWO, THREE, OR FOUR CARS; WHICHEVER PRODUCES THE MAXIMUM LOAD FOR THE ELEMENT UNDER CONSIDERATION.
3. THIS LOADING CORRESPONDS TO AW4 IN SECTION 12.3.A OF THE DCM. AW4 LOADING CORRESPONDS TO THE WEIGHT OF THE LRV PLUS 240 PERSONS.

EXHIBIT 5
Light Rail Vehicle Loading

Operations

The East Link operations plan is still under development during the completion of the Final EIS and preliminary engineering. In general, Link light rail would operate four-car trains, seven days per week, and provide service approximately 20 hours a day. A maximum headway of 10 minutes during peak periods is planned, with 15 minute-headways during the off-peak periods. Four-car trains would run during the peak, with three-car trains operating outside of the peak two hours.

Special Design Requirements

- The Track Bridge System shall be designed and detailed to accommodate floating bridge pontoon movements in all directions.
- The Track Bridge System shall be designed and detailed to provide adequate access to all components in order to facilitate inspection and maintenance activities. These access points shall be noted in the Inspection and Maintenance Manual discussed below. In the case where the existing modular expansion joints are left in place, secured access shall also be provided for their inspection and maintenance.

- The Track Bridge System shall be designed and detailed to mitigate the potential for fatigue damage of the supporting members.
- The Track Bridge System shall be designed with full consideration of stray current and cathodic protection requirements in accordance with East Link Design Criteria Manual.
- The attachments of the Track Bridge System, which includes the associated light rail tracks, shall be designed to preserve the structural integrity of the existing approaches, transition spans and main floating span, with no damage to the existing deck post-tensioning system, and minimal impact to the deck concrete and reinforcement by minimizing the number of mechanical anchorage embedments.
- The Track Bridge System shall be designed and detailed for operation at acceptable noise levels per FTA guidelines.
- Dynamic analyses shall be carried out in order to investigate the dynamic interactions between the light rail vehicle, Track Bridge System and floating bridge pontoons. The objective shall be to find a Track Bridge System stiffness that will minimize the dynamic load amplification while keeping the accelerations within rider comfort limits.
- Dynamic analysis results shall include stability, ride quality, vertical and lateral accelerations, and steady state and dynamic curving response predictions. The results of these analyses shall be later compared and verified with the full-scale prototype testing simulation results.
- Monitoring of the Track Bridge Prototype: the TBDC shall design a monitoring system that will be able to confirm that the design criteria and requirements are satisfied during testing. This function is essential to final acceptance of the prototype.
- Proposed control and monitoring system for revenue operations – design and specifications for a system capable of communicating Track Bridge System position and movements after installation on the Floating Bridge to Sound Transit Central Controls, either directly or via a local East Link systems relay station, both automatically and on demand. This controls system shall be tested in conjunction with the prototype Track Bridge.

Inspection and Maintenance Requirements

The Track Bridge System shall be designed such that the following conditions can be met once LRT is operational:

- Regularly scheduled preventive maintenance must be performed during non-revenue hours; it shall not be required more than once per month; and must be able to be accomplished in less than three hours for each Track Bridge System.
- Inspection, maintenance and adjustments outside of the regular maintenance schedule shall not be needed for all service conditions (lake levels and other displacements).

- For extreme conditions, inspection, maintenance and adjustments may be allowed to be more frequent than once per month, but may not exceed once per week, subject to Sound Transit approval.
- Absolutely no Track Bridge System operating condition, within the range of design movement, shall require maintenance or adjustments to be performed during revenue operating hours.

The TBDC shall prepare a Track Bridge System Inspection and Maintenance Manual to guide Sound Transit personnel in the proper inspection and maintenance of the Track Bridge System to keep them in good repair. This Inspection and Maintenance Manual shall define elements of the Track Bridge System that require maintenance, repair, rehabilitation, or replacement. The Inspection and Maintenance Manual shall include, as a minimum:

- As-Built Plans showing installation of components;
- Parts list identifying all parts used in the system to include manufacturer, part name, and part number;
- Contact information (physical address, e-mail contacts, Website, and phone numbers) for the manufacturer/supplier including contract names; and
- A Maintenance Log identifying the items to be maintained, frequency of maintenance, and maintenance procedures.

III. COMPUTER SIMULATION

Simulations allow the prediction of the vehicle running behavior and supporting structure response under environmental and transient loading conditions. The TBDC shall use a general multi-body rail vehicle dynamics computer simulation model capable of analyzing the dynamic interaction of rail vehicle and track to predict stability, ride quality, vertical and lateral dynamics, and steady state and dynamic curving response.

For the purpose of simulation, the TBDC can use commercially available software such as NUCARS, VAMPIRE, ADAMS/Rail, or equivalent.

To assess LRV response through imposed curves, the quotient of guiding force and vertical wheel force Y/Q (L/V), which is linked to Nadal's criterion, shall be calculated. The calculated wheel L/V ratio shall be less than 1.0.

Simulation Objectives

The overall objective is to validate the interaction between the proposed Track Bridge System and the existing supporting structure for structural stability, rail vehicle safety and rider comfort by simulating the passage of the Sound Transit light rail vehicle over the structure under multiple track movement scenarios. The specific objectives are to:

- Characterize the parameters of the existing ST light rail vehicle and the Track Bridge System (including the floating bridge pontoon behavior) required for an analytical simulation code to predict the response.
- Evaluate the static and dynamic performance of the proposed Track Bridge System, which includes the support system, under simulated environmental and transient loading conditions.
- Evaluate rail-structure interaction behavior.
- Evaluate the dynamic performance of the ST light rail vehicle under simulated environmental and transient loading conditions. Identify potential unsafe behavior of the car, such as wheel climb and wheel lift.
- Evaluate riding comfort based on ST DCM requirements.
- Confirm that the design satisfies the technical criteria and performance requirements.

IV. TESTING PROGRAM

The maximum levels of vertical and lateral misalignment and the maximum amount of crosslevel variation that can be safely and comfortably negotiated by a LRV are important factors during revenue operations. The dominant changes in the wheel/rail contact geometry due to local relative displacement between each wheel and the rail to which it is connected need to be carefully investigated to assure track-worthiness and vehicle operational safety.

In order to obtain information on the operability of the Track Bridge System and the bridging or replacement of the Homer Hadley bridge expansion joints, testing of a full-scale prototype assembly of the proposed structure with LRT rails attached on a testing facility is necessary. At a minimum, the Track Bridge System over an internal joint shall be tested.

Testing Considerations

The full-scale prototype Track bridge System and attached rails testing program should consider, but not be limited to, the following elements:

- Testing Facility – if possible, identify an existing suitable facility in which to perform the testing in order to reduce project costs.
- Test Vehicle and Propulsion System – specifications for the test vehicle matching the characteristics and anticipated loads of the existing Sound Transit light rail vehicle (see LRV data in Appendix B) and a propulsion system capable of operating the test vehicle across the prototype Track Bridge for the prescribed testing cycles.
- Test measurement and monitoring instrumentation – specifications for the types of instrumentation on the Track Bridge Prototype, support structure, rails and test vehicle, as applicable, to measure and record test performance. Instrumented wheel sets are recommended for measuring vertical, lateral and longitudinal wheel-rail contact forces across the range of the wheel tread and flange. Specifications for conducting testing and attainment of acceptance criteria.
- Test fatigue within service level conditions.

Testing Objective

The overall objective of full-scale testing is to confirm that the computer simulation results validate the design of the Track Bridge System as meeting the project technical requirements and Sound Transit design criteria.

Dynamic Tests

The battery of tests required to collect the data to demonstrate the acceptability of the prototype Track Bridge System shall be confirmed and detailed by the TBDC during design development and may include the following, at a minimum:

- Measurement – forces and movements of the Track Bridge System, which includes the rails on the support structure, during passage of the test vehicle across the testing assembly to obtain information about the dynamic behavior of the system.

- Static suspension system characterization – measuring the load-displacement characteristics for the primary and secondary suspensions.
- Rigid body modal characteristics – to obtain rigid body modal frequencies and damping of each dynamic vehicle mode.
- Track and wheel profile measurements – to obtain accurate input for simulation tests, using a portable profilometer.
- Dynamic testing for the following scenarios for comparison with computer simulations of lateral and vertical forces, including time-history plots: 1) yaw and sway; 2) twist and roll; and 3) pitch and bounce.
- Vehicle response to variations in vertical alignment – a "vertical bump" test using video cameras to measure the test car's capability to operate safely at permissible speeds over vertical curve alignments and to predict the potential of wheel lift.

Correlations Summary

Detailed correlations of simulation results with the test data shall be summarized. The dynamic response characteristics shall be correlated for all the track scenarios in the tests. These include, at a minimum:

- Maximum vertical wheel forces.
- Maximum lateral wheel forces.
- Minimum vertical wheel forces.
- RMS values for the vertical and lateral forces in the zone of track irregularity.
- Maximum carbody accelerations.

Prototype Acceptance Criteria

The testing of the prototype Track Bridge System shall culminate with the successful attainment of the following acceptance criteria, to be finalized during Phase 1:

- Fatigue
- Structure Design Criteria
  - Strength requirements meeting Sound Transit Design Criteria Manual
  - Deflection requirements meeting AREMA
- Rider Comfort
- Weight Requirements
- Noise per FTA guidelines
- Maintenance
- Operations

APPENDIX A

DETAILS OF CONCEPTUAL TRACK BRIDGE ASSEMBLY

Details of Conceptual Track Bridge Assembly

During Conceptual Engineering, the Sound Transit Conceptual Design Consultant prepared a conceptual design of Track Bridge. The following information is a description of that design.

Track Bridge Description

The function of the track bridge is to support the rails under wheel load conditions from the trains while allowing the imposed deflections due to bridge movements to be distributed over a longer length of track. If the imposed deflections bend the rail over a short distance, the stresses in the rail will be very high. If these deflections are allowed to take place over a longer distance, the resulting stresses will be significantly reduced.

The use of a track bridge system allows the imposed vertical angular deflections to be located at four locations. If the rail deflections were limited to just these four short locations, the rail stresses would still be too high. The system must allow enough vertical flexibility between the hinge locations so that the rail can curve smoothly over longer distances. The transfer beam system must also allow the horizontal deflections to take place over a reasonably long length so that the associated stresses in the rail are limited to an acceptable value.

At the same time, the design must provide a stiff enough system so that the deflections due to the passage of the loaded train are not so high that they adversely affect the performance of the train.

This conceptual design represents a feasible structural solution alternative. The design assumptions are to be confirmed based on further design development and review from a trackwork perspective shall the TBDC elect to pursue this alternative solution. Dimensions and other information in the following description are preliminary and subject to change as the design progresses. Rail fastener manufacturers shall also be consulted as the design of these joints advances.

Controlling Dimensions

An isometric view of the transfer beam system is shown in Exhibit A-1. As shown in Exhibit A-2, Track Bridge Framing Plan, the total length of the system is 41'-8" and the length of the center beam is currently 22′ – 6″. The distance between the pivot points is 12 feet. The end beams extend an additional 8′ – 5″ past the end of the center beam. The top of the rail is approximately 1′ - 3″ above the deck elevation.

A method to accommodate the track bridge is to provide a recess in the deck. This conceptual design layout requires a recess approximately 9 inches deep as shown in Exhibit A-3. The recess is required to maintain the standard plinth dimensions and to keep the added dead load as low as possible. However, providing a recess may require extensive modifications and may become costly. The other alternative to the recess is to gradually increase the plinth heights in the proximity of the expansion joints.

Structural Description

The track bridge concept proposes to use fabricated structural steel plate girder sections approximately 20 inches deep. The flanges are 6 inches wide and 1 inch thick. The center-to-center distance between the center and end beams is 8 inches.

The ends of the beams, which are supported by the deck, have curved bearing plates to accommodate the vertical rotation of beam ends relative to the support structure. The bearing plates will bear on sliding bearings, which accommodate the longitudinal movement of the transfer beams. Numerous options are available for these bearing surfaces.

Transverse guides are attached to the supporting structure as shown in Exhibit A-4. These steel fabrications provide a bearing surface to resist transverse loads. They also keep the beams from rotating. The interface between the center and end beams is also equipped with vertical bearing plates so that the transfer beam system maintains a constant width. The faces between the beams will be provided with a bearing material to allow for some deflection in the joints and a bearing surface to reduce the friction.

The transverse guides have to be long enough to allow the end of the beams to move through their entire range.

These transverse guides must have the capacity to resist both lateral loads from the train as well as loading due to the transverse rotation of the transition span relative to the adjacent structure. The pair of transverse guide sets at each end of the transfer beam apply a moment to the center area of the structure, which then will bend in a curve. This curve must be able to distribute the transverse bending in the rails over sufficient length to minimize the stresses in the rails. Some flexibility may be required in the bearings at the transverse guides to control the horizontal bending.

The pivot between the end and center beams is provided by a transverse shaft and bearings located in each beam. A bearing surface is located between the beams at this location to resist transverse loads. The bearing assembly at the two beams must also be able to resist tension so that the beams remain in contract.

Transverse beams between the beams on each side are formed by plate girder sections. They support the rail fasteners between the side beams. The plate section provides both the necessary structural capacity and fixity against rotation of the side beams.

Due to the longer length of the transfer beams, there are now more than two rail fasteners at each beam section. Some vertical flexibility must be provided so that the rails can maintain a relatively smooth curve due to angular deflections of the joint. Some of this vertical flexibility can be provided in the rail fasteners. If more is needed, springs can be installed between the top of the crossbeam.

Due to the longer length of the transfer beams, their deflection under live loads will become a bigger issue. This conceptual design minimized the depth of the beams. If this design is progressed, it may be possible to increase the depth of the beams without unacceptable consequences. It may also be possible to accommodate some of the live load deflections by cambering the transfer beams. The most practical way may be to adjust the rail geometry be shimming between the rail fasteners and the top of the crossbeams.

The typical spacing of cross beams and rail fasteners is 29 inches. The center-to-center distance between the last rail fastener located on a cross beam and the first rail fastener located on a concrete plinth is currently 24 inches. This allows the transfer beam to move 13 inches toward the support structure without interference between the fasteners. When the relative movement between the transfer beam and the structure expands, the center-to-center distance between fasteners is 37 inches. This spacing is somewhat larger than normal usage, but this condition will rarely occur, if ever, since it represents the maximum design event movement of the joint and not necessarily the actual movement. The frequency of these movements is the information that will be found by instrumenting the bridge joints at the transition spans. During final design, the frequency of this movement of the joint can be factored into the analysis of the joint and rails.

The best condition would be if the transfer beams remained centered between the adjoining structures. If the transfer beams are allowed to move toward one extreme or the other, it results in the spacing between rail fasteners being larger than necessary. The transfer beam structure will be provided with stops so that it is not necessary to keep it centered in the gap.

Due to the multiple motions required for this structure, a cable centering device is being considered. The cables would be anchored on one structure, pass 180 degrees around a sheave on the support beams, and return to the end of the opposite structure. When one structure moves longitudinally with respect to the other structure, the center support beams are constrained to move one-half the distance and remain centered. Some flexibility would be built into the cables so that they can accommodate the other motions required of the joint. The flexibility can be provided either by building some slack into the cables, or by providing springs at the anchorages.

There are other centering systems such as linkages that shall also be considered for the final design.

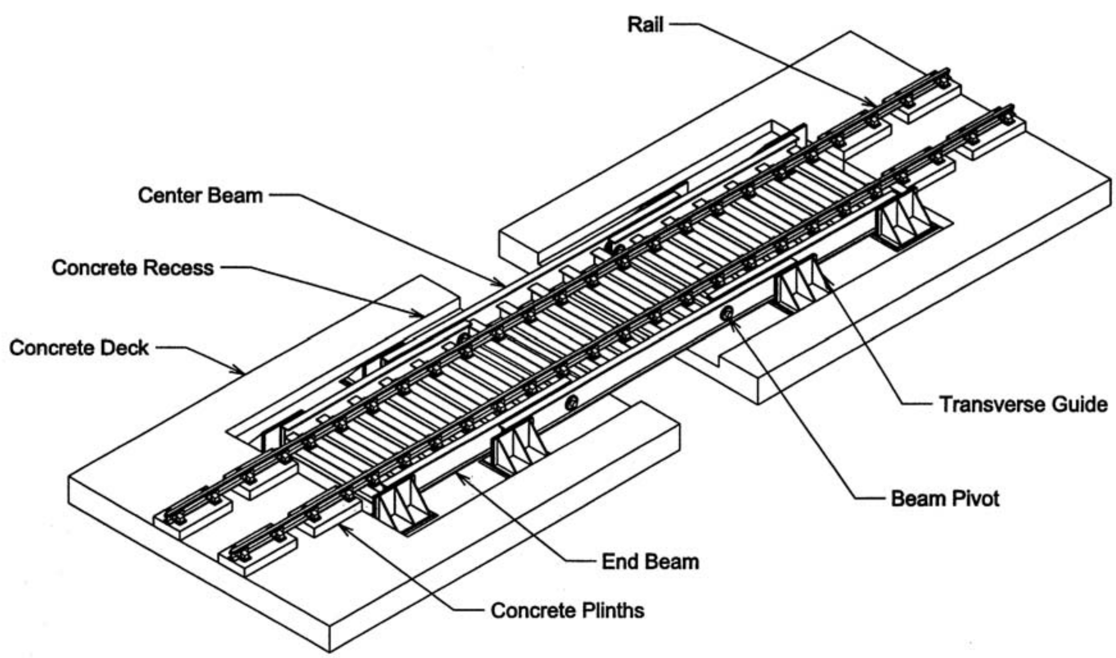


EXHIBIT A-1
Isometric View of Transfer Beam System

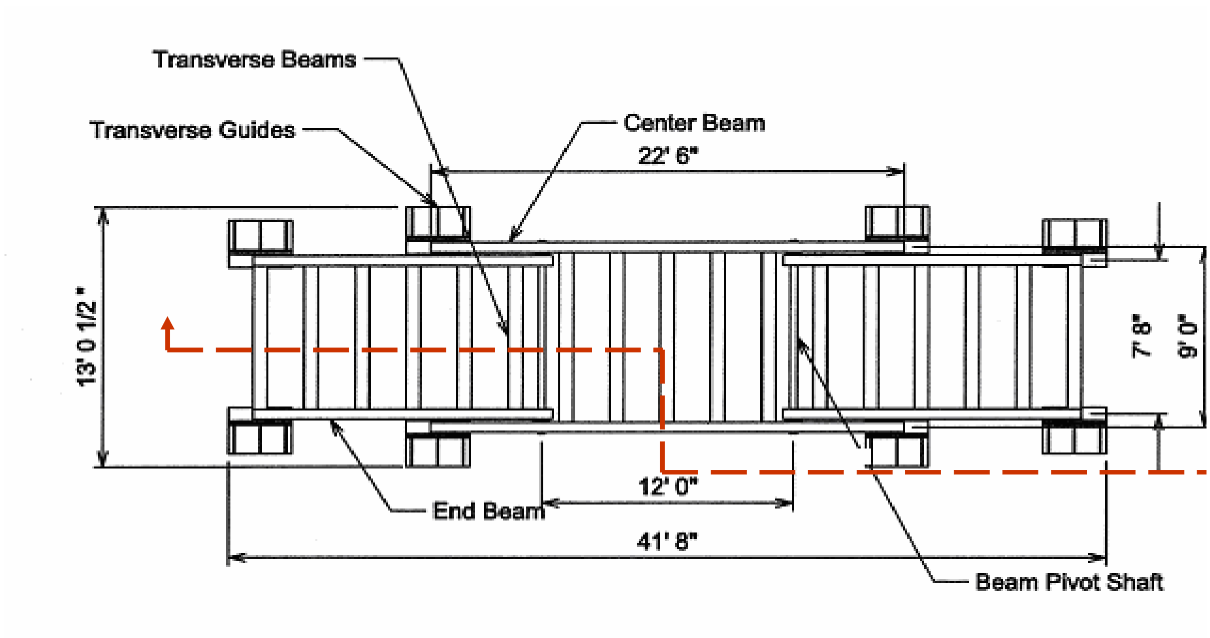


EXHIBIT A-2
Triple Beam Framing Plan

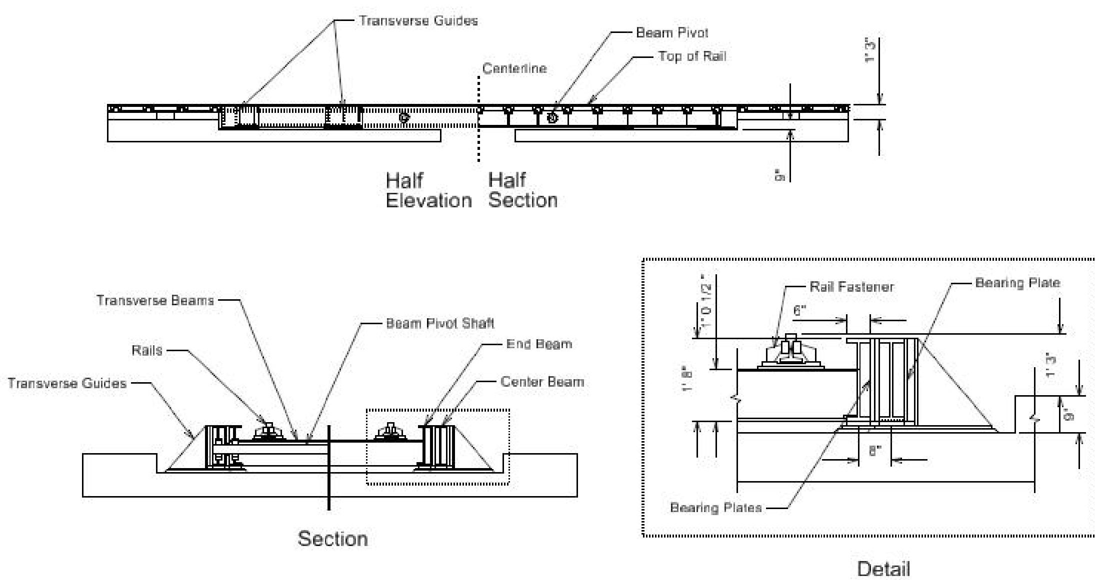


EXHIBIT A-3

Triple Beam System Sections

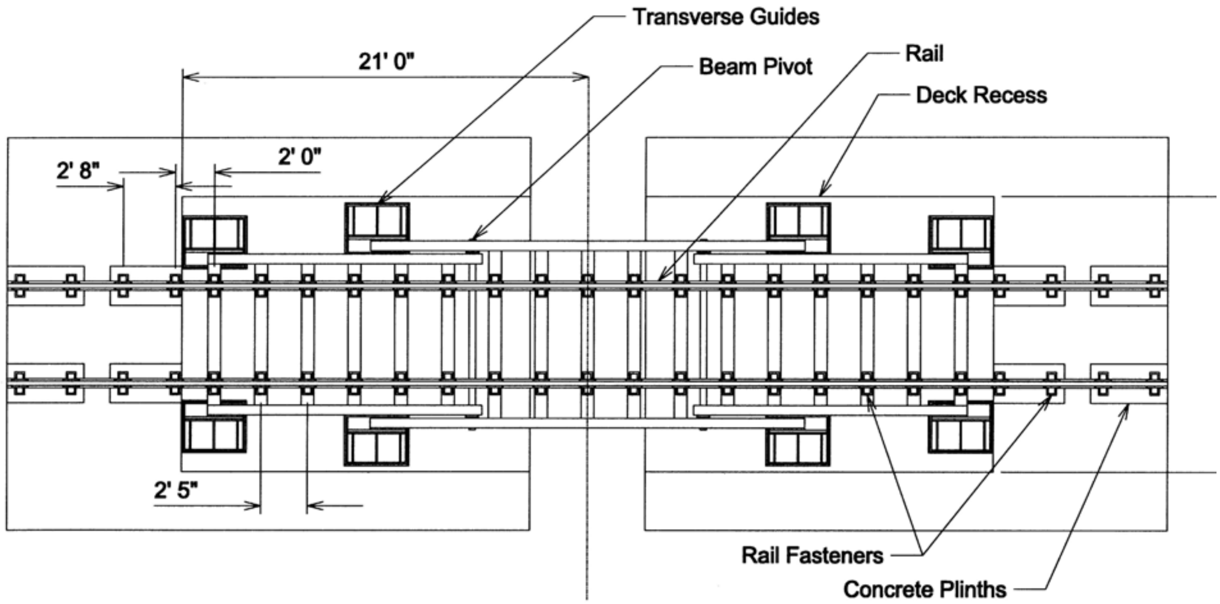


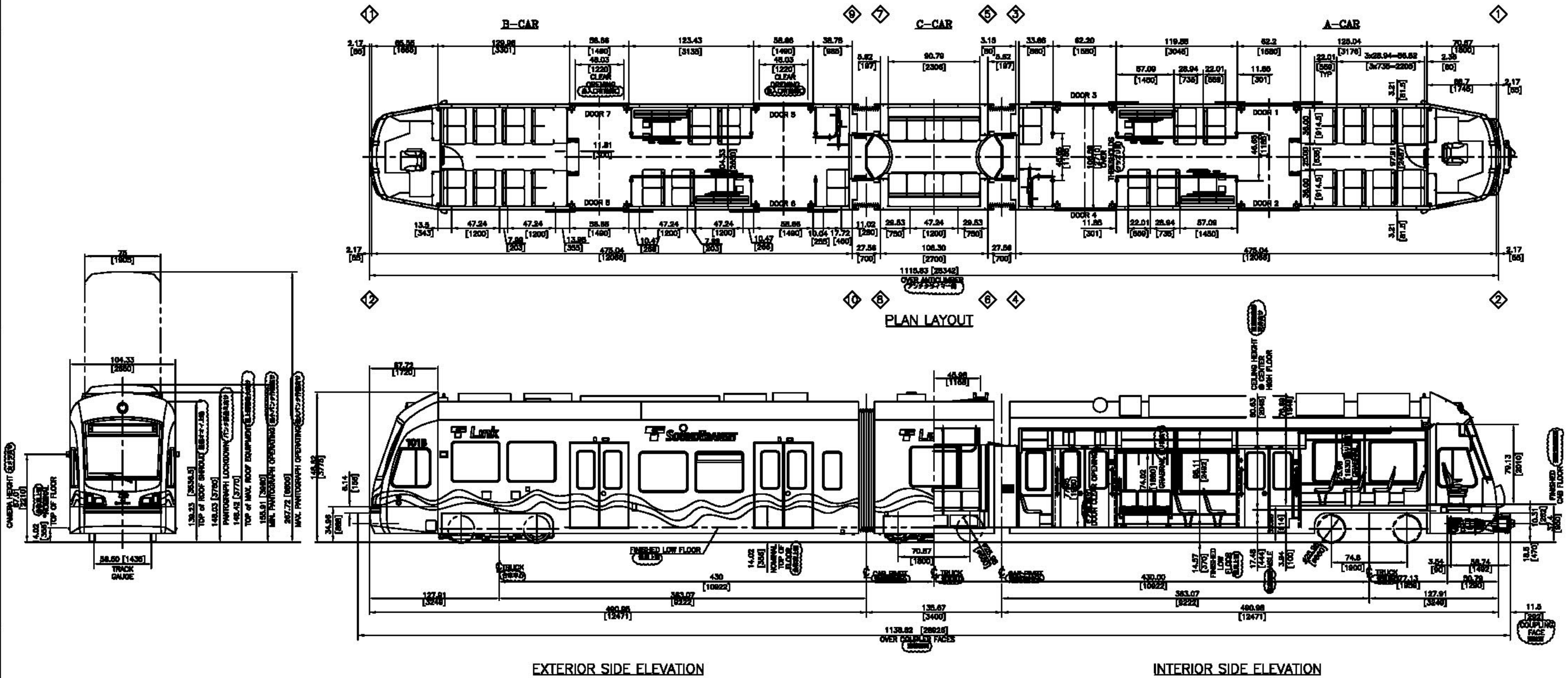
EXHIBIT A-4

Triple Beam Overall Plan

APPENDIX B

VEHICLE DATA

UD00720



NOTE

1. NOMINAL TOP OF FLOOR AT ENTRANCE IS EDGE OF THRESHOLD AT 14"(356 mm) FROM TOP-OF-RAIL. THE NOMINAL TOP OF FLOOR IS 0.55"(14 mm) BELOW THE FINISHED LOW FLOOR.

1. 公称床面高サハ、レール面上356mmニ位置スル、クツズリ角トスル。公称床面高サハ実際ノ完成床面高サヨリ、14 mm下ニ位置スル。

B	10/11/05	NUMEROUS UPDATES, PRIMARILY: EXT. GRAPHICS, REAR VIEW CAMERA, DOOR HEADER COVERS, BIKE RACK AREA, INFO HOLDERS, GRAB HANDLES (DAF) ADD COUPLER COVER (MM)
A	02/28/05	CHG. PANTO. WIDTH, ADD REAR VIEW CAMERA HEIGHT, UPDATE PANTO/ROOF EQUIP. HEIGH, ADD CAR & DOOR LOCATION DESIGNATION, ADD THRESHOLD DIM. ADD NOTE FOR TOP OF FLOOR, CHG. COUPLER HEIGHT (MM)

B14616	ST	MC2C	A	•	A101
B14616	ST	MC2B	A	•	A101
B14616	ST	MC2A	A	•	A101

APPROVED Y. SUGIMOTO
M. WAKUDA

KINKISHARYO Intl. LLC.
BOSTON, MA

DRAWING TITLE
GENERAL ARRANGEMENT
SEATTLE

DATE 1/16/04
SCALE 1:50
ORIG. DWG. SSM0001
UNIT OF MEASURE in/lb [mm/kg]
DRAWING NUMBER 1-UD00720
(REF. ONLY)

近畿車輛

CONTRACT NO. RTA/LR-101-02
DOC. CONTROL
MTL. CONTROL
NEXT HIGHER DWG. NAME
NEXT HIGHER DWG. NO.
GROUP NO. A101

ST-7141

				Variable Name			AW0			AW1			AW2			AW3		
Category	Part		Unit	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Mass	Car Body Mass		kg/body	mB_A	mB_B	mB_C	13499	14374	3777	15739	16684	4477	19659	20604	5037	21689	22634	5177
	Bolster Mass		kg/bogie	mSE	mSE	mSC	570	570	300	570	570	300	570	570	300	570	570	300
	Bogie Spring Mass		kg/bogie	mTE	mTE	mTC	4095	4095	1215	4095	4095	1215	4095	4095	1215	4095	4095	1215
	Bogie Unsprung Mass		kg/axle	mW	mW	mW	1955	1955	2635	1955	1955	2635	1955	1955	2635	1955	1955	2635
	Axle Box Mass		kg/box	mA	mA	mA	50	50	115	50	50	115	50	50	115	50	50	115
	Bolster Anchor Mass		kg/rod	mBAM	mBAM	mBAT	12	12	9.5	12	12	9.5	12	12	9.5	12	12	9.5
	Articulation Arm Mass		kg/body	mAP	mAP	-	50	50		50	50		50	50		50	50	
	Articulation Bearing Mass		kg/body	mAR	mAR	-	30	30		30	30		30	30		30	30	
	InterCar Z-link Mass		kg/rod	mRL	mRL	mRB	30	30	50	30	30	50	30	30	50	30	30	50
Inertia	Moment of Inertia, Car Body	Roll	k-m^2	IXBA	IXBB	IXBC	31600	33648	10787	36843	39056	12787	46020	48232	14386	50772	52984	14786
		Pitch	k-m^2	IYBA	IYBB	IYBC	173976	185253	6884	202846	215025	8159	253367	265546	9180	279530	291709	9435
		Yaw	k-m^2	IZBA	IZBB	IZBC	173976	185253	6884	202846	215025	8159	253367	265546	9180	279530	291709	9435
	Moment of Inertia, Bogie Sprung Mass	Roll	k-m^2	iXTE	iXTE	iXTC	1481	1481	1199	1481	1481	1199	1481	1481	1199	1481	1481	1199
		Pitch	k-m^2	iYTE	iYTE	IyTC	2184	2184	1767	2184	2184	1767	2184	2184	1767	2184	2184	1767
		Yaw	k-m^2	iZTE	iZTE	iZTC	3023	3023	2446	3023	3023	2446	3023	3023	2446	3023	3023	2446
Stiffness	Stiffness, Axle Box Guide	Vertical	N/mm/axle	k1_M	k1_M	k1_T	2430	2430	2650	2430	2430	2650	2430	2430	2650	2610	2610	2710
		Longitudinal	N/mm/axle	k1x_M	k1x_M	k1_x_T	32000	32000	32000	34320	34320	36280	37270	37270	41190	38250	38250	44130
		Lateral	N/mm/axle	k1y_M	k1y_M	k1y_T	4400	4400	4200	4610	4610	4510	4710	4710	4610	4810	4810	4710
	Stiffness, Bolset Spring	Vertical	N/mm/half bogie	k2_A	k2_B	k2_C	393	406	425	452	467	486	527	544	620	570	583	682
		Longitudinal	N/mm/half bogie	k2y_A	k2y_B	k2y_C	267	271	279	291	297	305	323	329	357	339	344	377
		Lateral	N/mm/half bogie	k2y_A	k2y_B	k2y_C	267	271	279	291	297	305	323	329	357	339	344	377
	Stiffness, Bolster Anchor	Vertical	N/mm/half bogie	k4_M	k4_M	k4_T	13700	13700	17000	13700	13700	17000	13700	13700	17000	13700	13700	17000
		Lateral	N/mm/half bogie	k4y_M	k4y_M	k4y_T	1610	1610	1650	1610	1610	1650	1610	1610	1650	1610	1610	1650
		Longitudinal	N/mm/half bogie	kB_M	kB_M	kB_T	13700	13700	17000	13700	13700	17000	13700	13700	17000	13700	13700	17000
	Stiffness, Articulation Rubber Bushing		N/m	kAR	kAR	kAR	115718470			115718470			115718470			115718470		
Damping	Axle Spring Damping		N-s/mm/bogie	c1_M	c1_M	c1_T	2.5	2.5	2.6	2.5	2.5	2.6	2.5	2.5	2.6	2.5	2.5	2.6
	Bolster Spring Damping		N-s/mm/bogie	c2_A	c2_B	c2_C	104.6	108.2	113.4	121.4	125.4	133.1	143.1	147.9	169.1	155.1	158.7	187.2
	Lateral Damper		N-s/mm/bogie	c2y_M	c2y_M	c2y_T	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5
	Articulation Damper		N-s/m	-	cRF	cRF		588000	588000		588000	588000		588000	588000		588000	588000
Vertical Dimension	Wheel Radius		m	rW			0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	Height of Center of Gravity of Car Body from Axle		m	h2_a	h2_B	h2_C	1.51	1.51	1.275	1.432	1.435	1.183	1.369	1.374	1.167	1.347	1.353	1.164

				Variable Name			AW0			AW1			AW2			AW3		
Category	Part		Unit	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	Height of Floor of Car Body from Rail		m	hF_M	hF_M	hF_T	0.89	0.89	0.35	0.89	0.89	0.35	0.89	0.89	0.35	0.89	0.89	0.35
	Height of Center of Gravity of Bolster from Axle		m	hSE	hSE	hSC	0.23	0.23	0.247	0.23	0.23	0.247	0.23	0.23	0.247	0.23	0.23	0.247
	Height of Side Bearing of Bogie from Axle		m	hSBR	hSBR	-	0.37	0.37		0.37	0.37		0.37	0.37		0.37	0.37	
	Height of Inter Car Z-Link from Rail		m	hRL			3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505	3.2505
	Height of Articulation Damper from Rail	Right	m	-	hRFR			3.252	3.252		3.252	3.252		3.252	3.252		3.252	3.252
		Left	m	-	hRFL			3.241	3.241		3.241	3.241		3.241	3.241		3.241	3.241
	Height of Center of Gravity of Bogie Sprung Mass from Axle		m	h1E	h1E	h1C	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Height of Bolster Spring from Axle		m	hAS_M	hAS_M	hAS_T	0.23	0.23	0.247	0.23	0.23	0.247	0.23	0.23	0.247	0.23	0.23	0.247
	Height of Lateral Damper form Axle		m	hLD_M	hLD_M	hLD_T	0.29	0.29	0.11	0.29	0.29	0.11	0.29	0.29	0.11	0.29	0.29	0.11
Longitudinal Dimension	Initial Position of Center Bogie		m			xC			15			15			15			15
	Distance between Bogie Centers		m	lCE	lCE	lCE	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922	10.922
	Distance from Articulation to Center Bogie		m	lAR	lAR	lAR	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
	Half of Wheel Base		m	a_M	a_M	a_T	0.95	0.95	0.9	0.95	0.95	0.9	0.95	0.95	0.9	0.95	0.95	0.9
	Longitudinal offset to CG of Carbody from Bogie Center		m	xB_A	xB_B	-	2.45	2.45		2.45	2.45		2.45	2.45		2.45	2.45	
	Length of Bolster Anchor		m	l4_M	l4_M	l4_T	0.65	0.65	0.45	0.65	0.65	0.45	0.65	0.65	0.45	0.65	0.65	0.45
Lateral Dimension	Half of Lateral Distance across Axle Springs		m	a1_M	a1_M	a1_T	0.575	0.575	0.5985	0.575	0.575	0.5985	0.575	0.575	0.5985	0.575	0.575	0.5985
	Half of Lateral distance across Bolster Springs		m	a2_M	a2_M	a2_T	0.92	0.92	0.9	0.92	0.92	0.9	0.92	0.92	0.9	0.92	0.92	0.9
	Half of Lateral Distance across Boletsr Anchors		m	aBA_M	aBA_M	aBA_T	1.16	1.16	1.05	1.16	1.16	1.05	1.16	1.16	1.05	1.16	1.16	1.05
	Lateral Offset of Lateral Damper	on Bolster	m	aLDB_M	aLDB_M	aLDB_F	1.12	1.12	0.9457	1.12	1.12	0.9457	1.12	1.12	0.9457	1.12	1.12	0.9457
		on Frame	m	aLDT_M	aLDT_M	aLDT_F	0.777	0.777	0.7355	0.777	0.777	0.7355	0.777	0.777	0.7355	0.777	0.777	0.7355
	Lateral Offset of Articulation Damper	Right	m			aRFR			0.45			0.45			0.45			0.45
		Left	m			aRFL			0.615			0.615			0.615			0.615
Others	Coefficient of Friction, Side Bearing		m	mu_SBR	mu_SBR		0.45	0.45		0.45	0.45		0.45	0.45		0.45	0.45	
	Outside Ratius, Side Bearing		m	ro_SBR	ro_SBR		0.25	0.25		0.25	0.25		0.25	0.25		0.25	0.25	
	Inside Ratius, Side Bearing		m	ri_SBR	ri_SBR		0	0		0	0		0	0		0	0	
	Clearance of Lateral Bumpstop		m	eLS_M	eLS_M	eLS_T	0.01	0.01	0.026	0.01	0.01	0.026	0.01	0.01	0.026	0.01	0.01	0.026

APPENDIX C

LAKE LEVEL CHANGE DATA – HYDROGRAPHS

Lake Level Change Data - Hydrographs

Exhibits C-1/C-2/C-3 shows the summary hydrographs for the Lake Washington from 1980 to 2007. Based on the hydrograph data, except for the months September, October and November of 1986, the lake level fluctuated between the Elevation 20.0 feet and 22.0 feet. The data also suggest that during the months of September, October and November 1986 the lake level has reached a low of El. 19.40 feet. This is the only time the lake level went below the Elevation 20.0 feet during the service life of the Homer Hadley Floating Bridge.

In the months of April, May, June and July, the lake level fluctuates between El. 21.0 feet and 22.0 feet. While, during the months of December, January and February, it fluctuates between the El. 20.0 feet and 21.0 feet. During the remaining months of the year, lake level stays between the El 20.0 feet and 22.0 feet.

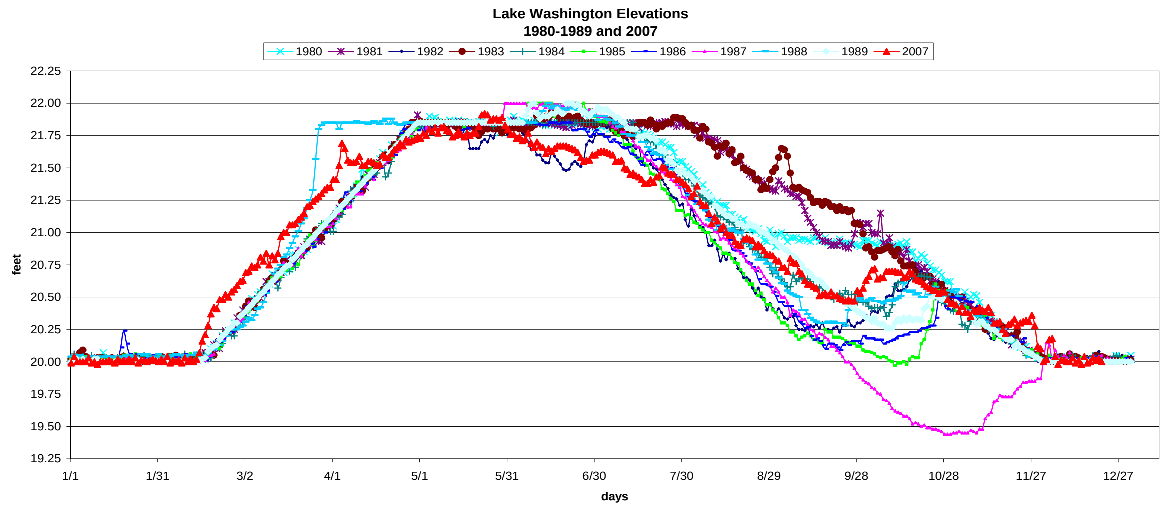


EXHIBIT C-1
Summary Hydrographs (from 1980 to 1989 and 2007)

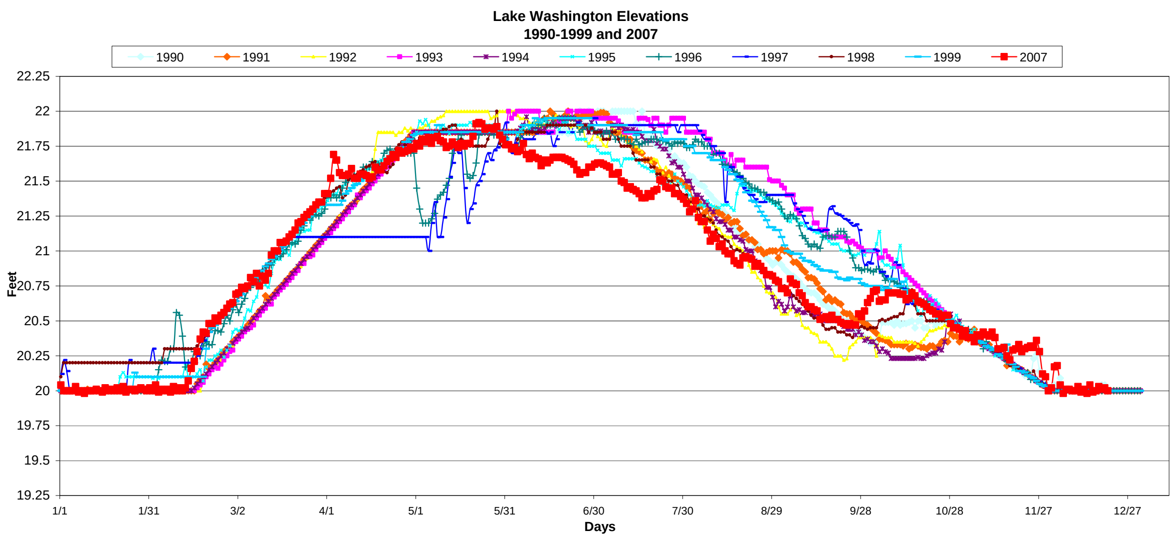


EXHIBIT C-2
Summary Hydrographs (from 1990 to 1999 and 2007)

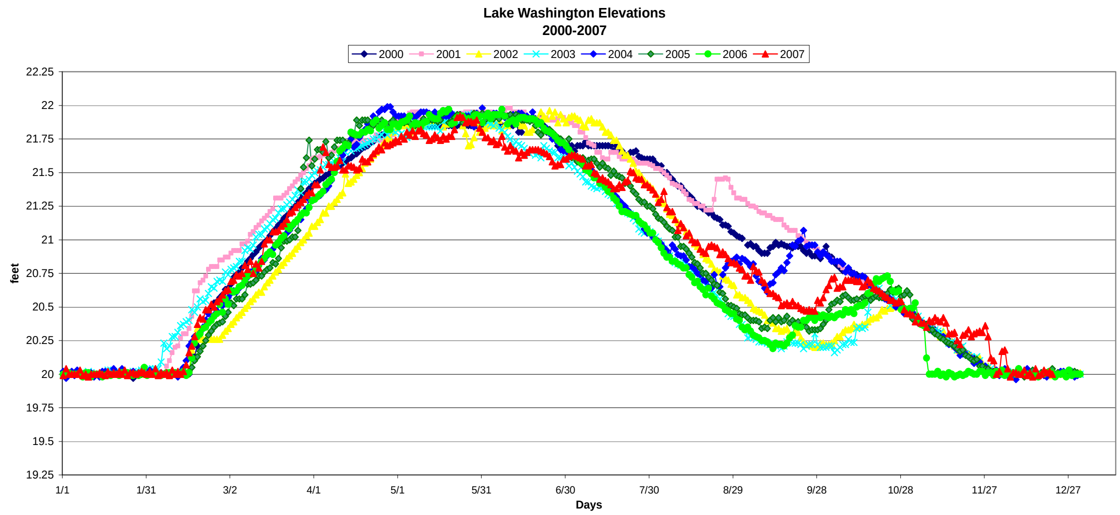


EXHIBIT C-3
Summary Hydrographs (from 2000 to 2007)