Phase 3: Decision Making for the Remaining Rehabilitation Needs and Tradeoffs

In 2012 the Washington State Seismic Safety Committee published the Resilient Washington State: Final Workshop Report which provides the framework for improving Washington's resilience when earthquakes occur by proactively reducing critical vulnerabilities. The framework is intended to facilitate long-term implementation of seismic risk reduction policies and activities across the state. www.seattle.gov/dpd/cms/groups/pan/@pan/documents/web_informational/dpds021970.pdf

Following that framework, WSDOT established a vision to refine its Phase three tier and create an interconnected lifeline of highways with built in redundancy to provide alternate routes if a segment of highway becomes impassable after an earthquake. To completely retrofit all of the phase 3 seismic lifeline routes, costs were estimated at well over $1 billion. With limited funding it would not be possible to secure essential lifeline routes in a timely manner.

WSDOT set priorities by focusing on the areas with the highest ground motion, population density and freight movement (i.e. Puget Sound). Within the greater Puget Sound area WSDOT evaluated a number of potential routes. The goal is to provide or restore essential services within 3-7 days and be fully operational within 3 months.

So, WSDOT identified a network of mainline routes that can provide the critical corridors needed to get emergency responders into damaged areas rapidly and the state economy (freight and goods) moving again as quickly as possible (green lines). The Seismic Lifeline routes map (right) shows the corridors needed to provide these essential services, primary routes are I-5, I-405 and I-90 mainline. Due to the high costs to retrofit the bridges in downtown Seattle (black line), SR99 provides an important north/south alternate route (yellow line) with connections to I-5 at the north and south ends.

WSDOT has invested nearly $150 million to complete phases one and two and to begin work on phase three substantially decreasing the risk of damage from earthquakes. Lifeline bridges (mainline only), highlighted in grey in the table to the right, are estimated at $100 million to implement phase three and secure the seismic lifeline routes in the greater Puget Sound. The Legislature funded $50 million (as of July 13, 2013) for the continuation of phase three which is well underway and will continue to decrease the risk of damage from earthquakes. This network will offer safe travel routes for vehicles and trucks during and after a catastrophic event.

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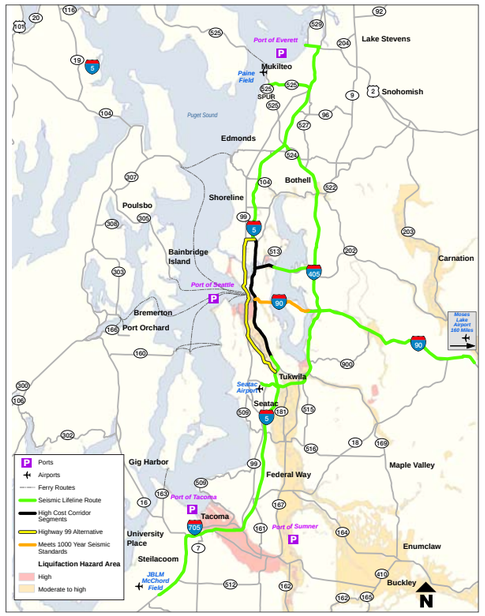
Bridge Seismic Lifeline Routes – November 2012



This lifeline network provides critical services (food, water, medical, etc.) and freight mobility on the east and west sides of Lake Washington

High Ground Motion (30-45) Bridges Remaining to Rehabilitate

	North bound	South bound	Northbound and Southbound	East bound	West bound	Ramps, Overcrossings and Collector Distibutor	Total
Lifeline	24	22	1	1	1	36	85
Puget Sound (excl. Lifeline)	43	44	1	20	24	147	279
Western Wa. (excl. Lifeline & Puget Sound	24	33	1	9	9	132	208
Grand Total	91	99	3	30	34	315	572

15-06-0232

Washington State Department of Transportation

June 2015

Seismic Lifeline Routes

Bridge Seismic Retrofit Program

Earthquake Challenges

Washington State has a long record of major earthquakes and is considered to be one of the five states facing the greatest seismic hazards in the United States. California and Washington are the two states at greatest risk.

Earthquakes can happen in Washington State at any time, and past history indicates there may be substantial shifting of land during a seismic event. Historically, the state has experienced earthquakes as high as a 6.8 magnitude, notably the Nisqually earthquake at 10:54 a.m. PST on February 28, 2001.

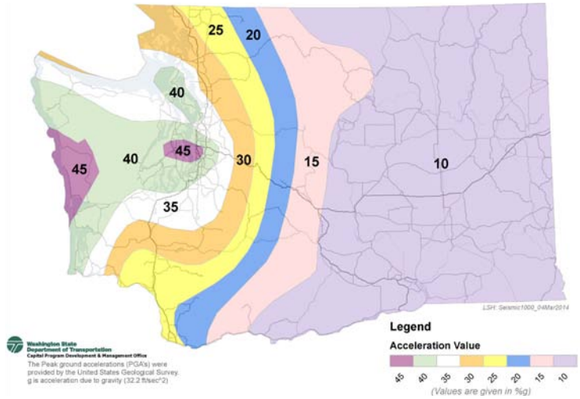
Of the ten active Puget Sound faults in western Washington State, seven of the faults are most likely to impact the main roadways that run through the heavily populated urban areas of that region. The highway system in Washington State is a vital economic resource. In 2011, $41.7 million of freight moved on Washington roadways hourly.

Goals & Objectives

Two of the Washington State Legislature's goals are to preserve assets and provide for economic growth. The **Washington State Department of Transportation (WSDOT)** manages 18,500 highway lane miles and more than 3,600 bridges on the state's highway system.

One of the agencies objectives is to ensure that state highways will be able to provide emergency responders access to damaged portions of the community quickly to provide essential life-saving services. State Highways will also need to provide the capability for the state economy and the movement of freight and goods to be restored as quickly as possible.

Earthquake Peak Ground Motion – 1000-Year Event



Ground Motion Severity of a 1,000 year Earthquake Event

In an earthquake, damage to buildings and infrastructure (bridges) is more closely related to ground motion rather than magnitude. In addition, the ground type can significantly influence ground acceleration. Base on the geographic area and historical data geologists are able to create seismic hazard maps which show likely earthquake ground motion zones. This map is a compilation of the fault zones in Washington. https://fortress.wa.gov/dnr/seismics-cenarios/index.html?config=cascadia.xml The values are used to determine the appropriate earthquake loading for structures within each zone. Zone 45 is the fastest acceleration zone and is the highest risk for damage.

Highway collapse, earthquake of 6.6 magnitude, San Fernando, CA 1971

WSDOT's Role: Risk Reduction to Minimize Damage due to Severe Ground Motion

To accomplish these program objectives in the area of seismic resiliency, WSDOT developed its initial seismic rehabilitation plan in the early 1990s to strengthen the bridges in Western Washington to withstand a 500 year seismic event that creates heavy ground motion due to the rupture of a fault along the coast or throughout the interior of Western Washington. In 2007, AASHTO updated its seismic standards to a 1000 year seismic event. WSDOT's plan identifies the number of structures built prior to the adoption of current seismic standards and vulnerable to damage from an earthquake. The Plan proposed a series of cost effective and nationally accepted measures to retrofit these bridges. WSDOT's seismic program is focused on minimizing potential damage to bridges; however it does not eliminate all risk of potential damage due to the severity of ground motion.

Three Phase Seismic Retrofit Plan

To reduce the risk as quickly as funding would allow, WSDOT developed a three phase approach to strengthen the most vulnerable structural elements first.

Phase One

Phase one secured the superstructure to their bridge piers/columns to withstand horizontal movement so the decks do not collapse as shown in the photos below.

Failed bridge, earthquake of 6.8 magnitude Kobe, Japan 1995

Superstructure Retrofit

Phase Two

Phase two addressed single column bridges since there is no redundant support for the structure. As in the example below the integrity of the column failed when the rebar buckled when the concrete core, which carried the vertical load, turns to rubble and falls out.

Failed bridge column as a result of the 1971 earthquake San Fernando Valley, California

Columns (as shown above) are being wrapped with a steel jacket to contain and stabilize the concrete column which prevents cracking and possible failure during an earthquake.

(See the example to the right of the Aurora Avenue Bridge retrofit.)

Phase Three

Phase three addressed wrapping the multi-column bridge piers by jacketing the column with steel (as done for single column bridges) to withstand vertical forces caused by the ground motion.

Due to the large number of multi-column bridges with a retrofit cost that exceeded $1 billion, WSDOT saw the need to further prioritize Phase 3 work.

Damage resulting from the Magnitude 6.6 earthquake, San Fernando Valley, California.

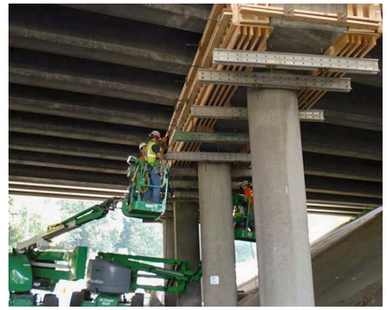
WSDOT worked with the State Department of Emergency Management, local emergency planners and freight advocates to identify a network of essential state highways in the areas of Puget Sound with the largest predicted ground motion and the highest density of population. Focusing limited resources on these routes further reduces the risk of major damage. This network of state highways is identified as the Seismic Lifeline Routes. The Seismic Lifeline program tracks the status of seismic retrofits made to high and moderate-risk bridges in the Puget Sound area which has the highest risk of acceleration (See the Seismic Lifeline Routes Map on the back). Further prioritization will occur as the bridges on this network are retrofitted.

Alternative Retrofit Options

To better withstand earthquakes, the typical way to retrofit a bridge is to wrap the column with a steel jacket. (as shown on the left)

But, the columns on the north end of the Aurora Avenue Bridge aren't typical. They were designed in the 30's and have a certain look and feel. To begin the columns were wrapped with rebar (as shown below). Then to keep that period look the columns were wrapped with a specialized carbon fiber reinforced polymer (similar to fiberglass but much stronger) that has the same strength as a steel jacket but keeps that Art Deco look.

This is what a column looks like when we "wrap" it with rebar to help stabilize the concrete. The concrete may crack, but the new reinforcing steel will keep the concrete from turning to rubble and falling out.



Crossbeam bolsters consist of adding reinforced concrete to the sides of existing crossbeams (the beam that sits on top of the columns). The purpose of these bolsters is to increase the crossbeam shear and moment capacity…As well as to increase the seat width… so girders don't fall off the crossbeam.

Girder stops are blocks of reinforced concrete that are installed between girders at the abutments and intermediate piers. The girder stops prevent the girders from sliding sideways on the abutment/pier.

Status: How Much Progress Has Been Made through 2013?

Since WSDOT's seismic retrofit program began in 1991, WSDOT has invested nearly $150 million to strengthen bridges to withstand earthquakes.

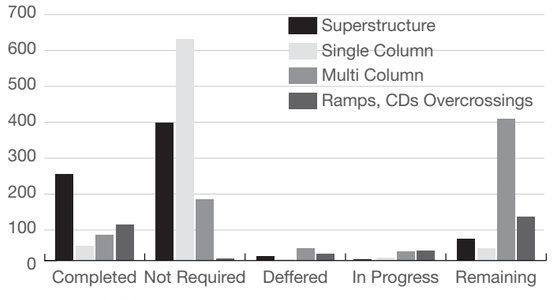
Using this phased approach WSDOT calculated "retrofit units". A retrofit unit identifies retrofit needs by the superstructure, single or multi-column bridge. (As shown in the chart) Meaning an individual bridge may have two retrofit units; one for the superstructure and one for retrofitting the columns.

Approximately 1600 retrofit units are either completed, identified that no retrofit is required, or the retrofit is deferred. Most deferred structures will be replaced in the near future.

Approximately 60 retrofit units are either partially complete or in progress. Approximately 600 retrofit units remain to be retrofitted. See the back page of this folio for more information on the decision making process and tradeoffs for the remaining rehabilitation needs.

Status: Statewide Bridge Retrofit Units

1991-2013



Data source: WSDOT Bridge & Structures Office.