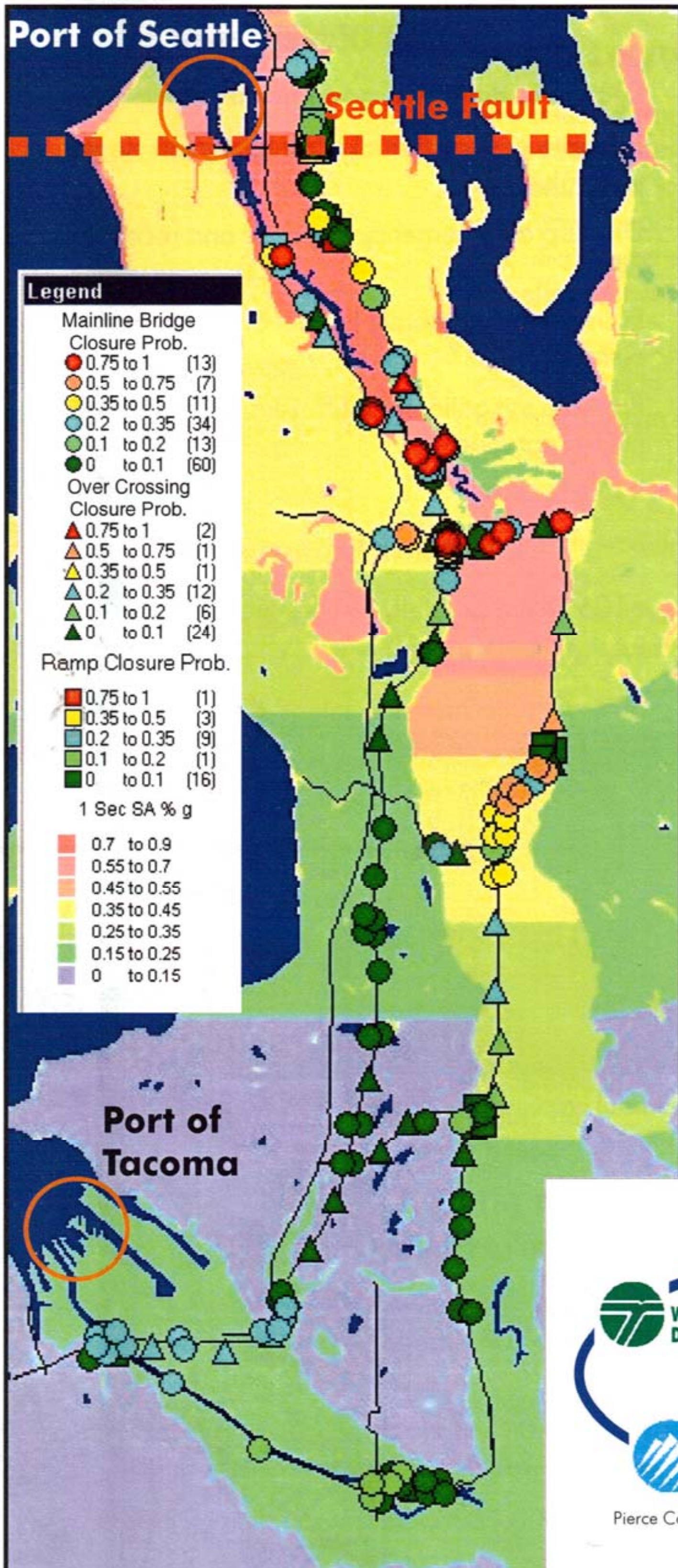
Building a Disaster Resistant Community

PROJECT IMPACT

Port to Port Transportation Corridor Vulnerability Mitigation

A Partnership between King and Pierce Counties Washington, "Creating Disaster Resistant Communities"



Expected Bridge Damage for Magnitude 6.5 Earthquake on the Seattle Fault (# of bridge closures in parenthesis)

USGS science for a changing world
Washington State Department of Transportation
Western States Seismic Policy Council
US Department of Transportation
EQE International
King County
Pierce County

Funding for this brochure and the accompanying web site was provided by the US Department of Transportation and the Western States Seismic Policy Council.

Project Partners

Private

- American Red Cross
- Bank of America
- BECU
- Boeing
- BNSF Railroad
- EQE International
- Frank Russell Company
- Gordon Trucking
- KOMOABC4
- Microsoft
- Olympic Pipe Line
- Tacoma-Pierce County Chamber of Commerce
- WSSPC

Public

- FEMA
- King County
- Pierce County
- Port of Seattle
- Port of Tacoma
- Sound Transit
- University of Washington
- USDOT
- USGS
- Washington Military Dept.
- WSDCTED
- WSDNR
- WSDOT

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INTRODUCTION

Project Objectives

- Engage business and government participation.
- Evaluate post-earthquake transportation system survivability.
- Develop an emergency response and recovery plan.
- Estimate the economic impact of transportation system outage.
- Promote mitigation of high-risk bridges on critical lifeline corridors.

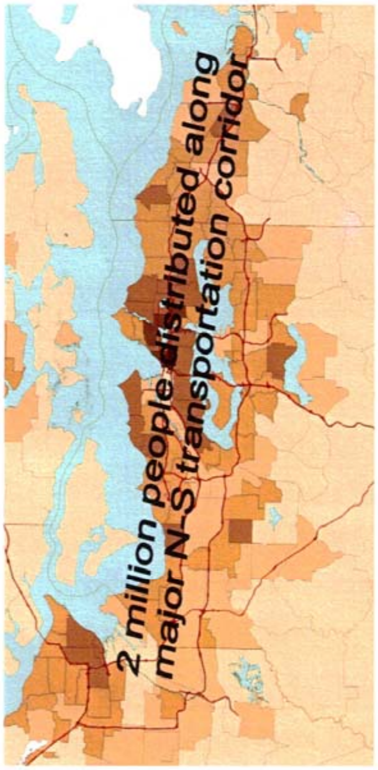
Economic Importance

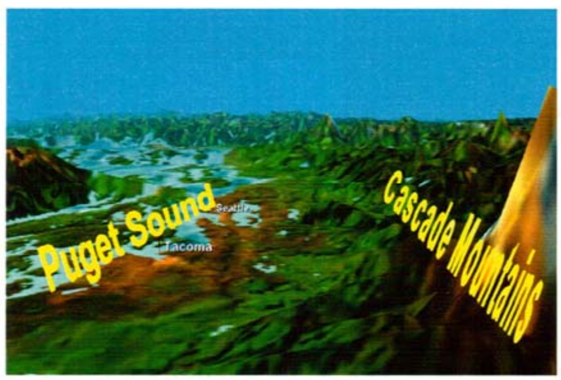
- $106 billion annually through ports
- 7% of U.S. trade with 2% of the population
- 60% of cargo moves to inland domestic markets
- Washington is most trade dependent state: 1 in 3 jobs dependent on international trade.

Project Location
The transportation corridor connects the ports of Seattle and Tacoma in Washington State's Puget Sound region.

Project Location/ Pilot Project

- The selected transportation corridor connects Tacoma/ Pierce County and Seattle/ King County. I-5 north of downtown Seattle, and I-405 were specifically excluded so as to balance the effort between the two counties.
- The study is designed to be a pilot project so as to focus on the selected corridor that provides a critical transportation link between the ports of Seattle and Tacoma.
- The study was designed to avoid major structures such as the Alaska Way Viaduct, to maintain focus on "system" reliability issues.



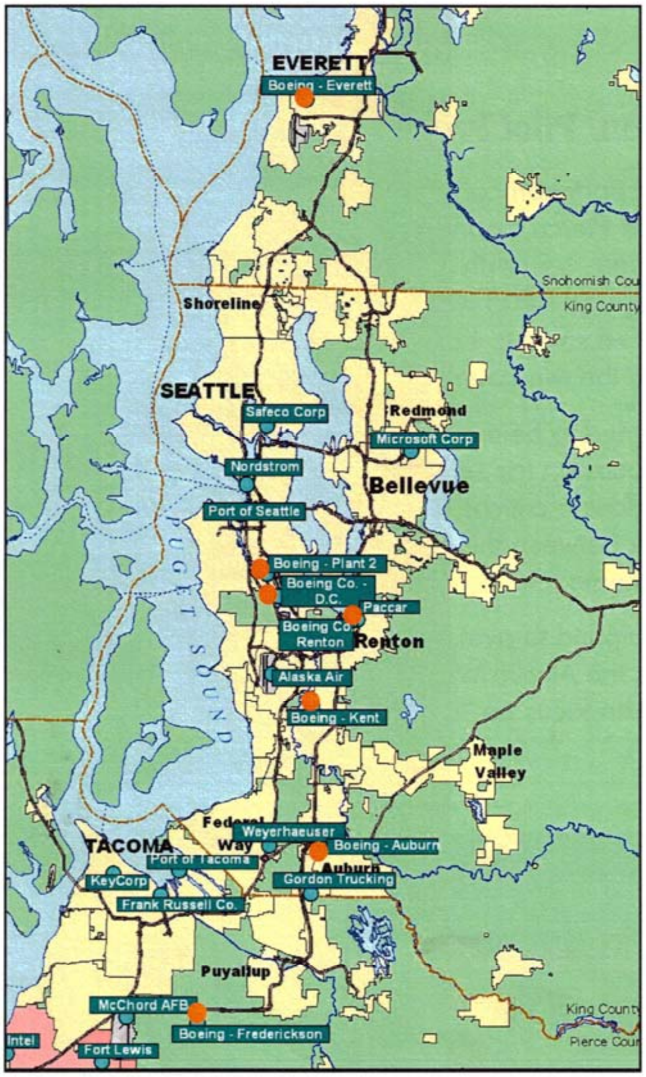


Puget Sound and the Cascade Mountains limit E-W growth.

Minimal highway redundancy makes detours very difficult.

- I-5 (▬)carries approximately 200,000 vehicles/day where it enters Seattle, and about 150,000 vehicles/day where it leaves Tacoma .
- SR-167 (▬) carries about 100,000 vehicles per day where it intersects I-405, with lower volume to the south.
- SR-99 (▬) carries about 25,000 vehicles per day.
- Each of the 3 routes are at capacity during rush hour, so there is little opportunity for detours should I-5 or SR-167 be out of service.

INTRODUCTION/ RISK ASSESSMENT APPROACH



Map of study corridor showing key employers (Boeing facilities identified by red dot. ●)

Business Dependence

- Employers must get people to work.
- Boeing, the nation's largest exporter, is dependent on highways for manufacturing . They move airplane wing assemblies over the highways from their manufacturing facility in Frederickson, furthest to the south, to assembly plants in Renton, and Everett, furthest to the north.

Risk Assessment Approach

- Hazard assessment
- Bridge reliability
- Evaluate route reliability
- Emergency response and recovery
- Economic impact

Use of HAZUS

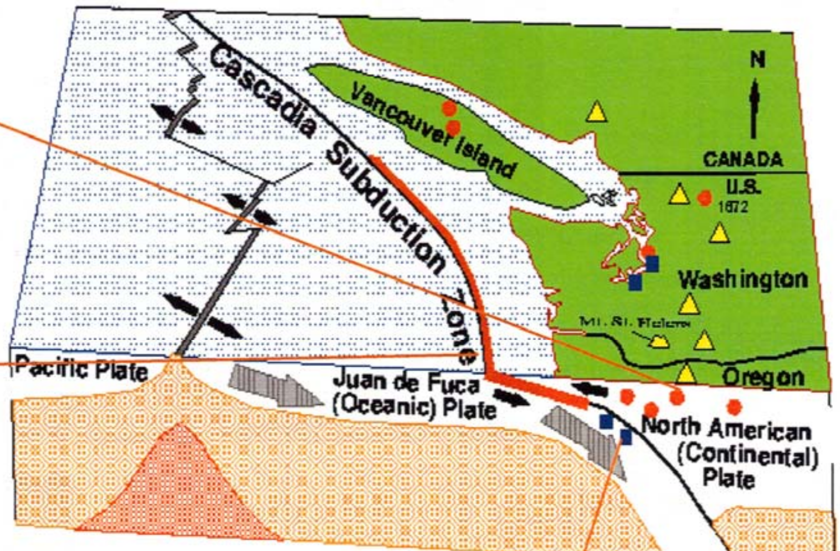
- HAZUS is being used as a tool to assist in the loss estimation process.
- HAZUS, developed by FEMA, runs on a GIS platform. Both MapInfo and ArcView versions are available.
- HAZUS is a convenient tool to load data and quickly evaluate a range of scenarios.
- "Black Box" issue: For example, during this study, it was identified that fragilities associated with liquefaction were not included in the results. The results did not look correct, but the user could not identify the problem by reviewing code. The problem was finally resolved with a software patch. Results require careful review.

EARTHQUAKE HAZARDS

Puget Sound Earthquake Source Zones

1) Crustal Earthquakes (< 15 miles) occur within the North American Plate on faults such as the Seattle, Tacoma, and South Whidbey Island. Seattle and Tacoma Fault scenarios are evaluated.

2) Cascadia Subduction Earthquakes occur about every 500 years at the boundary between the Juan de Fuca and North American plates. M9 event January 26, 1700. An M9 scenario is evaluated.



Graphic and scenarios by USGS

3) Deep Earthquakes—(>40 miles) occur within the subducting Juan de Fuca Plate. Five M6 events in last century. M6.5 and 7.1 scenarios are evaluated.

Seattle Fault

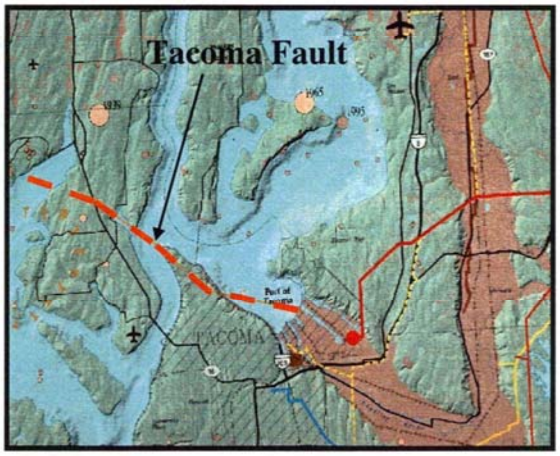
1. Deep basins in Puget Sound suggest major offsets along the Seattle, and possibly Tacoma faults.
2. Aeromagnetic, Seismic Hazards In Puget Sound (SHIPS), and laser (LIDAR) mapping have clarified that the Seattle fault exists.

3. Paleoseismic evidence of magnitude 7+ event with 22 feet vertical offset about 930 AD. Two more events identified in last few thousand years .
4. Geologists have identified multiple possible locations where the Seattle Fault is exposed.

Overview—Earthquake Hazard Scenarios

- HAZUS, the loss estimation tool used in this study to assist in estimating earthquake damage, uses peak ground acceleration, PGA, to estimate liquefaction probability, and 1 second spectral acceleration, SA, to estimate bridge damage.
- Unamplified and amplified PGAs and SAs, along with site amplification factors are shown for the Seattle M6.5 scenario. The 1 second SAs are shown for other scenarios. Both amplified PGA and SA maps are shown for the M9.0 Cascadia Subduction scenario to show that there is less attenuation of longer period ground motions (SAs).
- Ground motions are mapped thematically with consistent coloring for all earthquake scenarios.

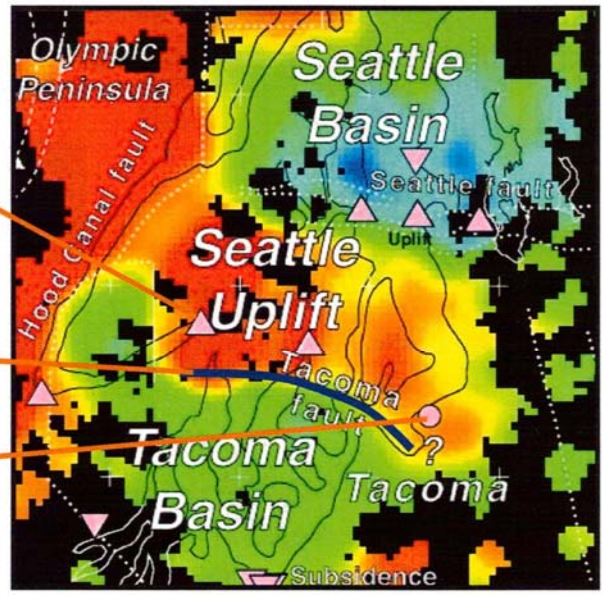
Tacoma Fault



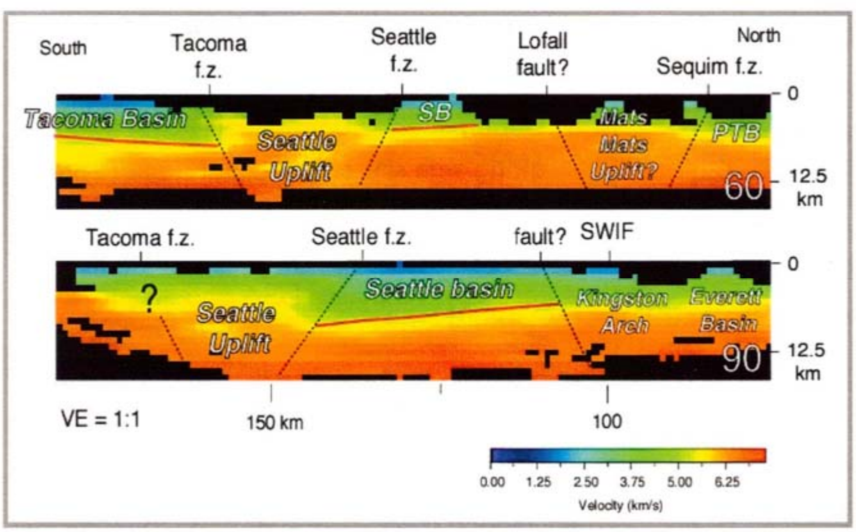
There is less known about the Tacoma Fault than the Seattle Fault that parallels it to the north. There is no known surface expression. It appears to mirror the Seattle Fault bounding an uplift zone.

Crustal Primary Wave Velocities Delineate Tacoma Fault

- There is paleoseismic evidence of significant uplift on the north side of the Tacoma Fault, towards the western end of the fault in an event that occurred about 1,100 years ago.
- A sharp change in P-wave velocities delineates the Tacoma Fault.
- There was minimal uplift toward the eastern end of the fault in the same event, so it may be less active near Tacoma.



Graphics by Brocher at the USGS.



Cross sections through the top 15 km of crust show the likely locations of the Tacoma and Seattle faults.

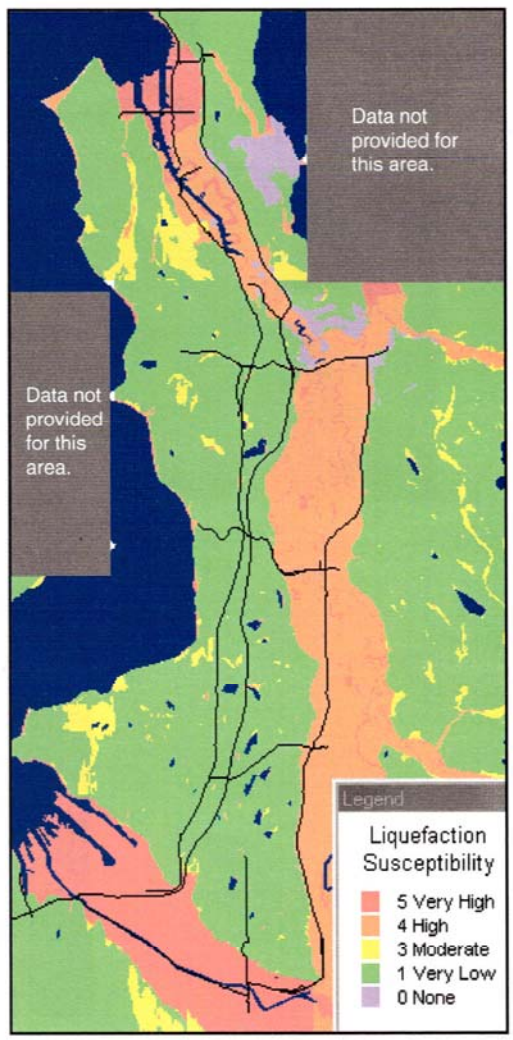
EARTHQUAKE HAZARDS
Soil Type and Liquefaction

Soil Type

- The site soil classification shown on the soils map is used to select the site amplification factor. This study used the site amplification factors developed in NEHRP-97 as a starting point, and modified (reduced) them to better relate the shear wave velocities used in the development of attenuation relationships with the shear wave velocities defined in the site soil classes.
- Site amplification was incorporated in the user provided ground motion map files used in this HAZUS analysis. HAZUS will not use soil site classifications to amplify user provided ground motions.

Liquefaction

- There is a high liquefaction susceptibility in many valleys in the Puget Sound region because of high water tables in river valleys with young geologic deposits.
- HAZUS incorporates a magnitude scaling factor and a displacement correction factor to better adjust for the duration of shaking in larger (or smaller) earthquakes.
- HAZUS used the Liquefaction Severity Index, LSI, to estimate lateral spreading.
- Liquefaction susceptibility mapping, developed by the Washington State Department of Natural Resources, was used to estimate liquefaction.

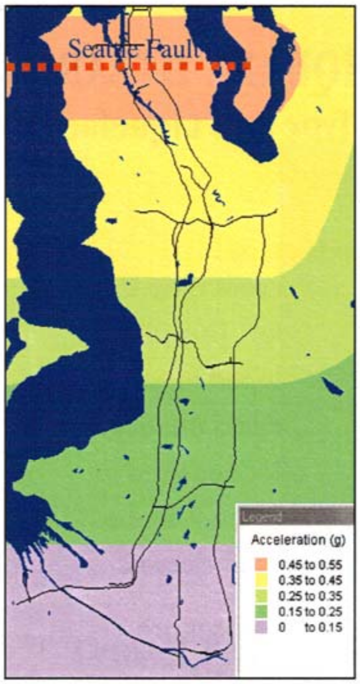


EARTHQUAKE HAZARDS

Ground Motion

USGS-provided ground motions are amplified depending on soil type, input ground motion intensity, and period. The resulting ground motions are input into HAZUS.

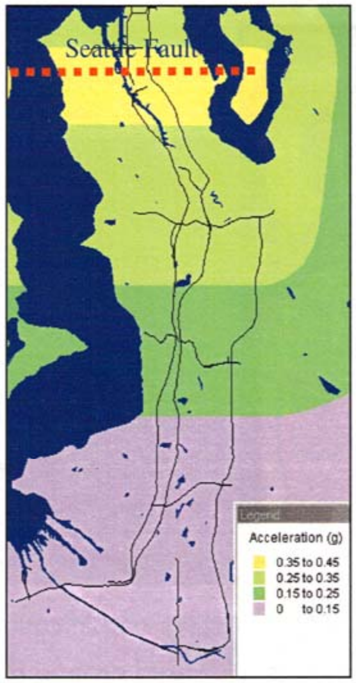
This is an example using a Seattle magnitude 6.5 earthquake event.



Peak Ground Accelerations for an M6.5 Earthquake on the Seattle Fault (No Site Amplification

Unamplified Ground Motions

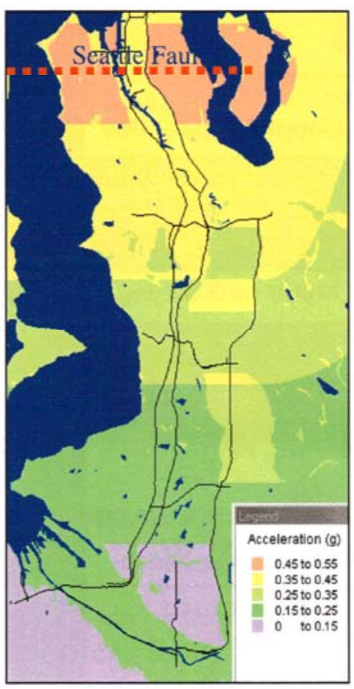
1.0 Second Spectral Acceleration for an M6.5 Earthquake on the Seattle Fault (No Site Amplification)



Peak Ground Acceleration Site Amplification Factors for an M6.5 Earthquake on the Seattle Fault

Site Amplification Motions

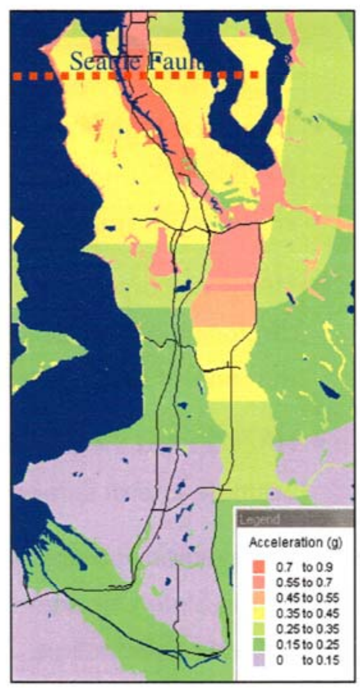
1.0 Second Spectral Acceleration Site Amplification Factors for an M6.5 Earthquake on the



Peak Ground Accelerations for an M6.5 Earthquake on the Seattle Fault

Amplified Ground Motions

1.0 Second Spectral Acceleration for an M6.5 Earthquake on the Seattle Fault

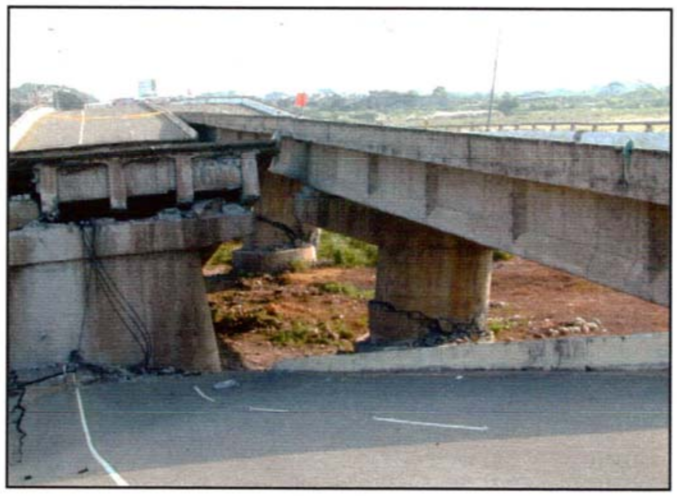


BRIDGE RELIABILITY

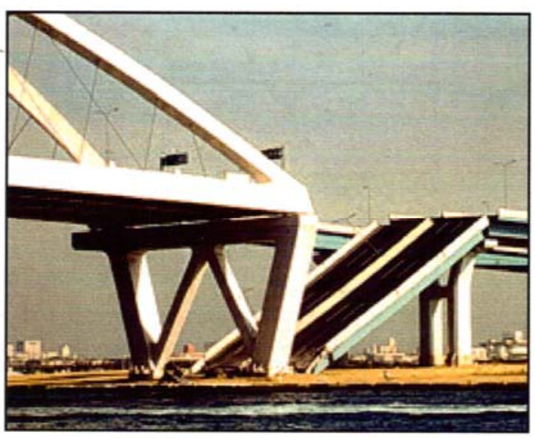
Damage relationships (fragility curves) relate earthquake hazard parameters and bridge reliability.

- Earthquake hazard parameters considered include:
    - Shaking / site amplification
    - Liquefaction/Lateral spread
- Fragility curves consider:
    - Structural design codes and detailing. (I-5 constructed in late 1950's - 1960's)
    - Empirical/historical performance of similar structures.
    - Structural/push-over analysis

Bridge pier rotated due to liquefaction.
Luzon, Philippines, 1990.

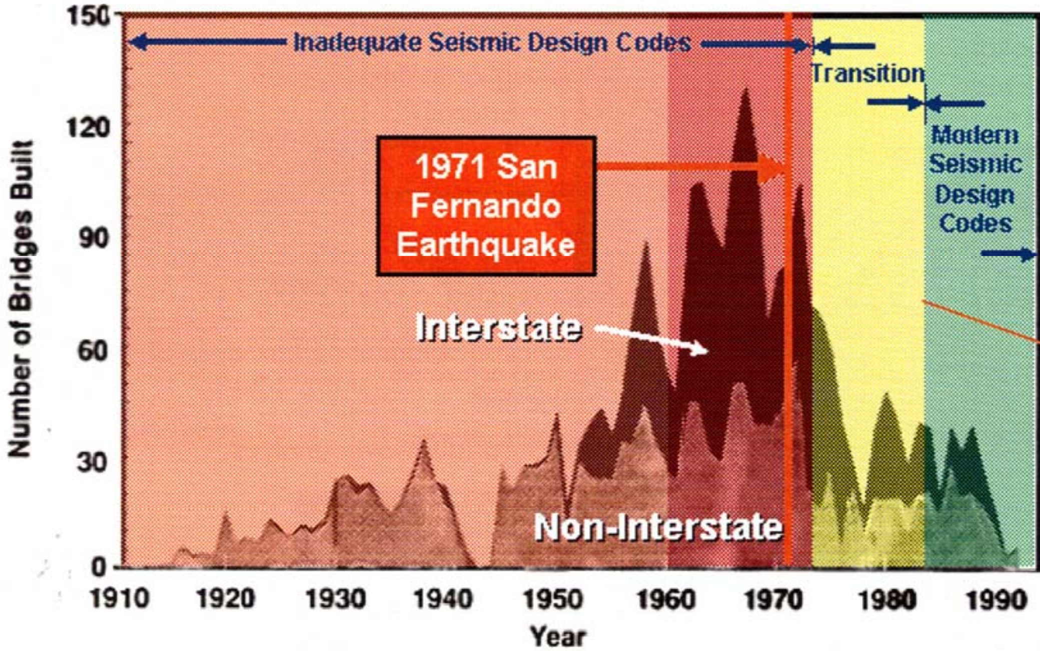


Bridge damaged by shaking.
Chi Chi Taiwan, 1999.



Bridge approach pulled off seat.
Kobe, Japan, 1995.

Washington State Highway Bridges
Years Constructed and Design Codes



The WSDoT began to use ASHTO seismic design codes in the early 1980's before they were adopted nationally.

Most of Washington State's bridges were constructed before adequate bridge seismic design codes were in place.

Bridge Fragility Curves

The inventory was categorized by bridge type, and bridge classifications/ fragility curves assigned to each.

Fragility curves included in HAZUS were used as a starting point and evaluated using push over analyses for typical bridges.

Bridge fragility curves within each category are modified based on its skew angle, the span length, the number of spans, and its width.

Bridges are categorized by design type and expected performance.

~ 1/3 of the bridges in the study area are Bridge Class HWB17.

The most vulnerable bridges (lowest structural capacity, ~ 44% x g) are classes HWB 5, 12, and 17.

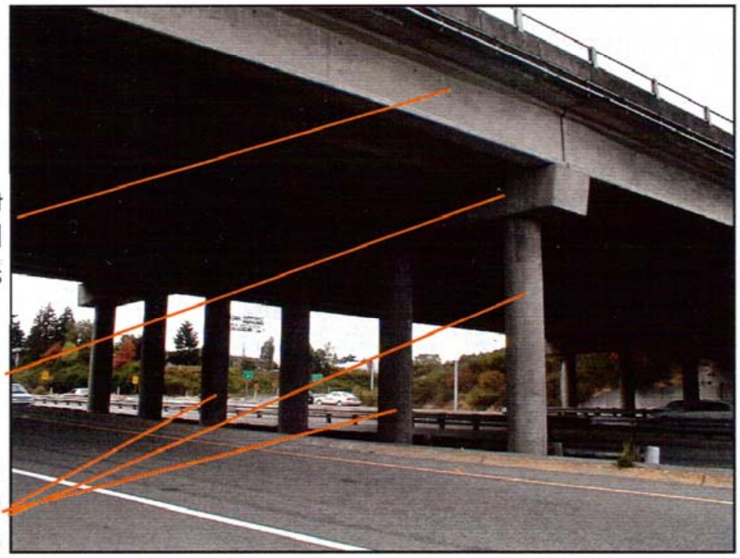
Bridge Class	Total		Capacity 1sec SA (g)	Bridge Type
HWB10	87	38%	1.05	Continuous Concrete
HWB17	74	32%	0.44	Multi-Col. Bent, Simple Support – P/T Concrete
HWB22	28	12%	1.05	Continuous – Prestressed Concrete
HWB3	8	4%	1.1	Single Span
HWB23	8	4%	1.05	Continuous – Prestressed Concrete
HWB12	4	2%	0.44	Multi-Col. Bent, Simple Support – Steel
HWB11	3	1%	1.05	Continuous Concrete
HWB15	3	1%	0.76	Continuous Steel
HWB4	2	1%	1.1	Single Span
HWB5	1	0.40%	0.44	Multi-Col. Bent, Simple Support – Concrete
HWB19	1	0.40%	1.05	Multi-Col. Bent, Simple Support – P/T Concrete

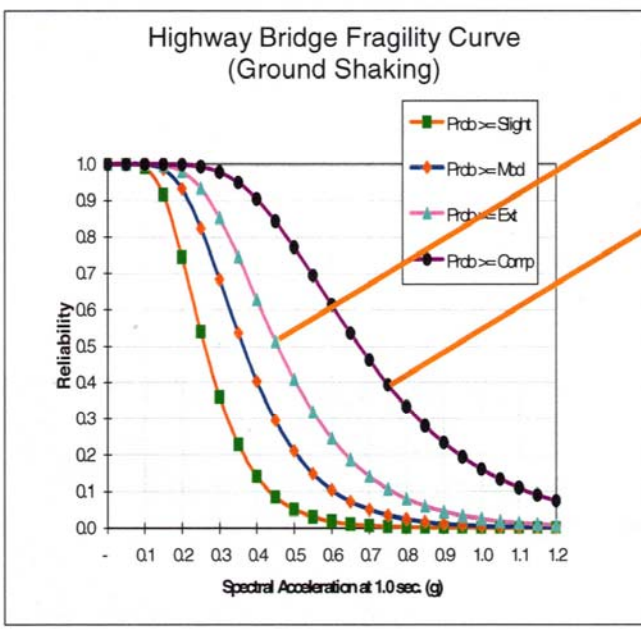
Typical HWB17 Bridge

Simple Support Post-Tensioned Concrete Girders

Bents

Supported on Multiple Columns



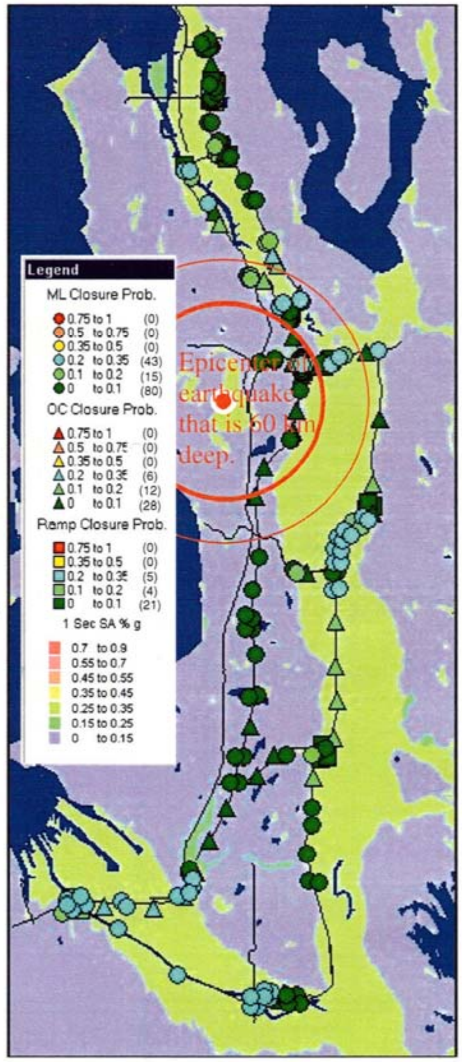


1. No damage
2. Slight damage (minor cracking/spalling)
3. Moderate damage (column shear cracks)
4. Extensive damage (columns structurally unsafe, major settlement at approaches)
5. Complete damage (column collapse, imminent roadway deck collapse)

Damage states 4 and 5 result in loss of functionality, and are of primary interest.

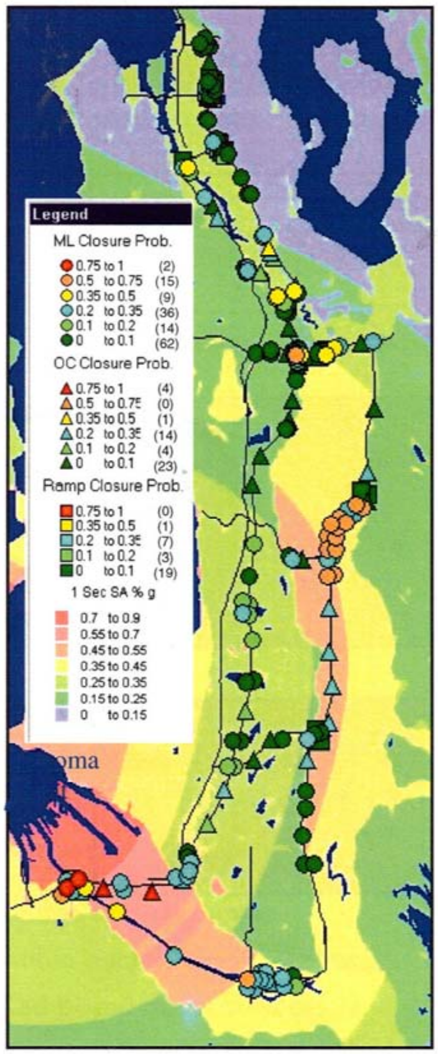
BRIDGE DAMAGE ESTIMATES

- Bridges were grouped into 3 types: 1) main line (ML), 2) overcrossing (OC), and 3) on/off ramps. Maps are shown for the 3 types combined, and for each type separately (see next page).
- Main bridges are the most critical, as detour routes would be required if the bridges were not available. Detours around major obstacles such as rivers may be a problem.
- Collapsed overcrossings can be removed in much less time than it takes to construct a new bridge. Collapse of overcrossings can divide communities.
- Ramp failures would require accessing the highway at a different location, but should have limited impact on use of the main line. In general, ramps were found to have limited vulnerability.



Benioff M7.1, main line, overcrossings, and on/off ramps.

- Closure probabilities shown on the legend are for bridges that are in the "extensive" or "complete" damage state, that will require significant time to repair/restore.
- Bridges with "moderate" damage (less than extensive), may require some repair before they are reopened to traffic.
- Bridge damage states are shown thematically by color. The coloring is consistent for all bridge types, and for all scenarios.
- The most vulnerable bridges (i.e. shown in red) are layered on top, and may cover less vulnerable bridges underneath.



Tacoma M6.7, main line, overcrossings, and on/off ramps.

Most Fragile Bridges
Damage State General Findings

- Date of construction: designed before adequate seismic codes were in place (prior to early-1970's)
- Type of design (multi- column bent, simple support)
- Site amplification (>200% in valleys)
- Founded on liquefiable soils (in valleys)

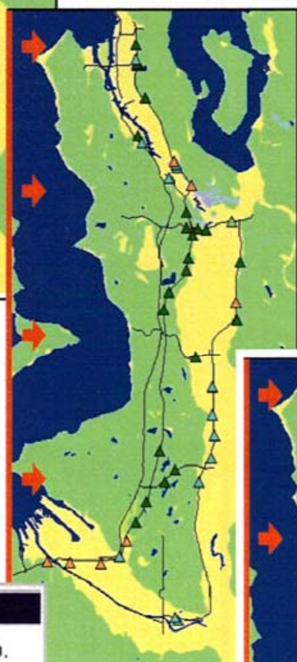
BRIDGE DAMAGE ESTIMATES

Magnitude 9.0 Cascadia Subduction Earthquake

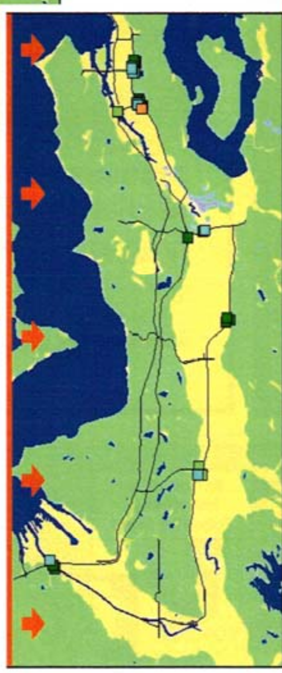
bridge damage, broken down into mainline, overcrossing, and ramp damage.

Mainline (ML)

Overcrossing



On/Off Ramp



All Bridges

Legend

ML Closure Prob.

- 0.75 to 1 (10)
- 0.5 to 0.75 (18)
- 0.35 to 0.5 (4)
- 0.2 to 0.35 (32)
- 0.1 to 0.2 (10)
- 0 to 0.1 (64)

OC Closure Prob.

- 0.75 to 1 (0)
- 0.5 to 0.75 (7)
- 0.35 to 0.5 (0)
- 0.2 to 0.35 (13)
- 0.1 to 0.2 (1)
- 0 to 0.1 (25)

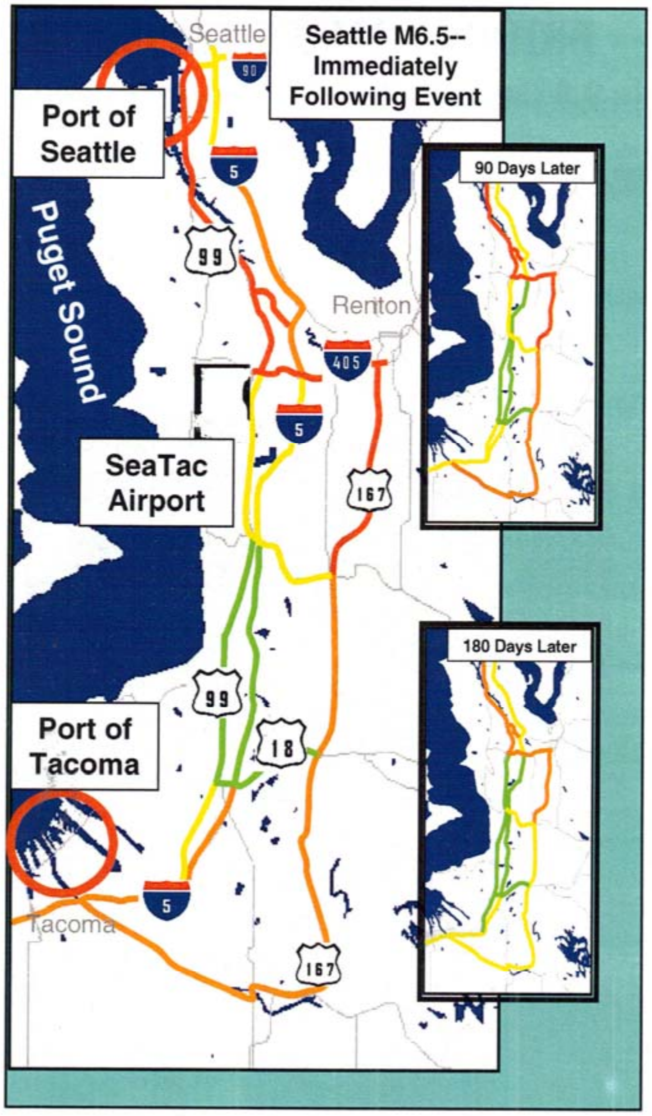
Ramp Closure Prob.

- 0.5 to 0.75 (1)
- 0.35 to 0.5 (0)
- 0.2 to 0.35 (8)
- 0.1 to 0.2 (4)
- 0 to 0.1 (17)

1 Sec SA % g

- 0.7 to 0.9
- 0.55 to 0.7
- 0.45 to 0.55
- 0.35 to 0.45
- 0.25 to 0.35
- 0.15 to 0.25
- 0 to 0.15

Number of bridges shown in parenthesis



ROUTE RELIABILITY AND RESTORATION

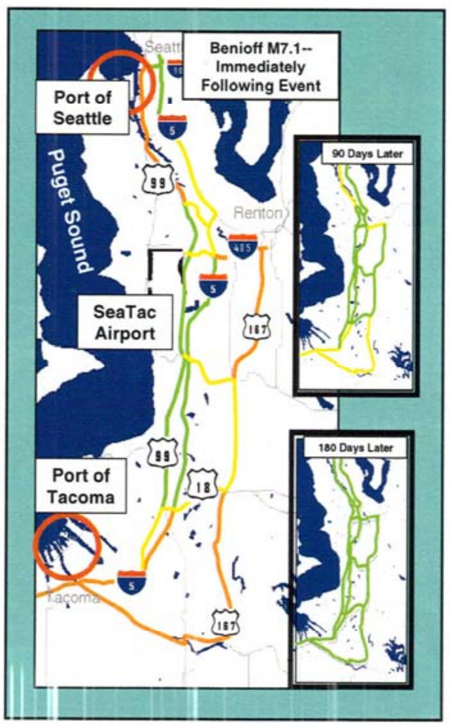
- The segment closure probabilities are shown for four earthquakes in three time frames: immediately following the event, and 90 and 180 days after the event. All bridges should be restored to full service within 365 days after all but the Cascadia Subduction earthquake, where there is greater than a 15 probability that some highways segments will remain closed for greater than one year.

- The closure probability of route segments immediately following the earthquake event is calculated by combining the probabilities of failure of the individual bridges within the segment.

Closure Probability

- >90%
- >50%
- >15%
- <15%

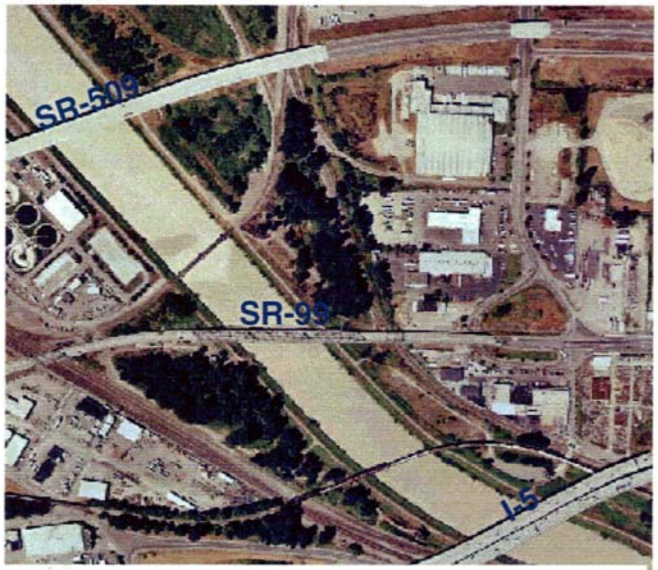
- A bridge restoration function is applied to each bridge to estimate its probability of being available at various time intervals after the earthquake. The segment closure probabilities are based on the bridge with the longest expected outage time in each segment.



EMERGENCY RESPONSE PLANNING AND ECONOMIC IMPACT ASSESSMENT

Emergency Response Planning

- Contingency planning – particularly river crossings
- Corridor restoration approaches



The Puyallup River in Pierce County poses a major geographic barrier. The river is bounded by liquefiable soils, making the I-5 bridge in particular vulnerable to earthquakes. The County is developing contingency plans for detours on parallel bridges should the I-5 bridge fail. Detour capacity is much less than the capacity of I-5.

The Duwamish River in King County is another major barrier along the north-south corridor. The I-5 bridge is a critical structure because it also crosses the BNSF Railroad track that provides an alternate form of transportation between Tacoma and Seattle. The next major bridge that crosses the Duwamish River is 6 miles downstream.

Significant Economic Impact Expected

- Northridge Earthquake: estimated $1.5 billion transportation-related business interruption loss
- Los Angeles highway network much more redundant than Seattle region's
- Objective: evaluate potential transportation disruption effects on businesses and the regional economy for earthquake scenarios

Economic Impact Assessment Analysis Approach

1. Interview local businesses, develop case studies.
    - Provide scenarios to businesses
    - Evaluate likely impacts
2. Estimate order-of-magnitude regional economic loss.
    - Using existing Input-Output type model of Puget Sound economy
    - Incorporating case study findings and information from Northridge, etc.
3. Produce report, including case studies and loss estimate.

Business Interviews

- Cross-section of industries
- Major employers & small businesses

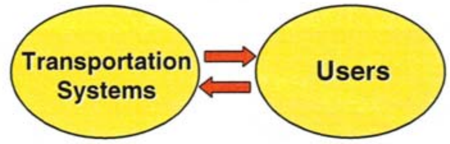
SUMMARY AND CONTACT INFORMATION

Transportation Corridor Critical to the Economy - Regional and National

- $106 billion, 7% of U.S. trade through ports.
- 60% moves to inland markets.
- 2 million people work/live along N-S corridor-rerouting is not possible.
- Employers depend on highways and rail for manufacturing, and getting people to work.

Summary of Project Elements

- Business and government partnership.



- Evaluate post-earthquake transportation system survivability.
- Develop an emergency response and recovery plan.
- Estimate the economic impact of transportation system outage.

Contact Information and Links

- Project Web Site http://www.rspa.dot.gov/oet then click on the Special Studies button
- King County Office of Emergency Management
  Internet Address http://www.metro.kc.gov/prepare
- Pierce County Department of Emergency Management
  Internet Address http://www.co.pierce.wa.us/abtus/ourorg/dem/abtusdem.htm
- Pierce—King Counties Project Impact Phone (253) 798-7428;
  e-mail pckcprojimpact@co.pierce.wa.us
- EQE International, Seattle, Washington Donald Ballantyne, Project Manager
  Phone 206-624-8687; e-mail dbballan@eqe.com; Internet Address http://www.eqe.com
- Western States Seismic Policy Council
  Internet Address http://www.wsspc.org
- U.S. Federal Emergency Management Agency—Project Impact
  Internet Address http://www.fema.gov/impact
- U.S. Department of Transportation
  Internet Address http://www.dot.gov
- U.S. Geological Survey
  Internet Address http://geohazards.cr.usgs.gov/pacnw/index.html