Understanding Earthquake Hazards in Washington State

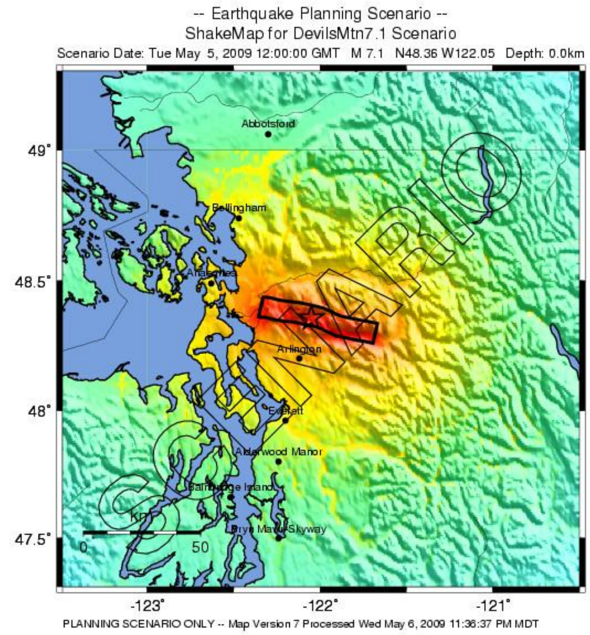
Modeling a Magnitude 7.1 Earthquake on the Darrington–Devils Mountain Fault Zone in Skagit County

Geologic Description

This M7.1 earthquake scenario is based on a 50 kilometer (31 mile)-long rupture of the Darrington–Devils Mountain fault zone between Mount Vernon and Darrington. This fault zone forms the northern boundary of the Everett basin and lies along a series of high-amplitude aeromagnetic anomalies that extend from the Cascade Mountains to Vancouver Island, B.C.

This fault zone was originally named the Devils Mountain fault for exposures on Devils Mountain near Mount Vernon, Washington, where it separates Mesozoic rocks from Tertiary deposits. Later, another segment, called the Darrington fault zone, was identified where northeast-trending faults juxtapose Mesozoic mélange against Eocene rocks near the town of Darrington. In 1994, the two zones were combined into the Darrington–Devils Mountain fault zone (DDMFZ).

Lidar (light detection and ranging) mapping along this fault zone revealed several potential fault scarps. Trenches across scarps on Whidbey Island exposed faulted and folded glaciomarine drift. Mostly high-angle reverse faults (with a few normal faults and low-angle reverse faults), these display approximately 1 to 4.5 meters (3–15 feet) of vertical separation and about 2 meters (6.5 feet) of left-lateral displacement. Radiocarbon ages from these trenches show that the deformation likely occurred during two earthquakes: the first 1,100 to 2,200 years ago; the second 100 to 500 years ago. Three trenches excavated across a low scarp (less than 1 meter [3 feet] high) east of Mount Vernon exposed faulted glacial deposits and sheared bedrock, with vertical separation of approximately 0.5 meter (1.6 feet).



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. ShakeMap for a M7.1 earthquake on the Darrington–Devil's Mountain fault zone. The black polygon is the modeled fault rupture surface.

Flower structures and abrupt facies changes across faults suggest a component of lateral slip: trenches excavated parallel to faults exposed offset glacial channels and bedrock shears indicating right-lateral displacement of 1 to 3.5 meters (3–11.5 feet).

Type of Earthquake

Most earthquake hazards result from ground shaking caused by seismic waves that radiate out from a fault when it ruptures. Seismic waves transmit the energy released by the earthquake: the bigger the quake, the larger the waves and the longer they last. Several factors affect the strength, duration, and pattern of shaking:

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- The type of rock and sediment layers that the waves travel through.
- The dimensions and orientation of the fault and the characteristics of rapid slippage along it during an earthquake.
- How close the rupture is to the surface of the ground.

Deep vs. Shallow: The M7.1 scenario earthquake modeled for the Darrington–Devils Mountain fault zone is a shallow or crustal earthquake. Shallow earthquakes tend to be much more damaging than deep quakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes the seismic waves have lost more energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.1 shallow earthquake like the one in this scenario would likely be followed by many after-shocks, a few of which could be large enough to cause damage.

Figure 2. Sinking and collapse of a building as a result of liquefaction during the 1989 Loma Prieta earthquake in San Francisco, California. (Photo: J.K. Nakata/USGS)

Other Earthquake Effects

Tsunamis: Some earthquakes may rupture a fault at the surface of the ground. If this fault offsets the floor of Puget Sound, it could generate a local tsunami. Delta failures and landslides caused by the shaking may also create or amplify tsunamis. Geological and historical evidence shows that landslides and failures of the sediments in river deltas have generated tsunamis within Puget Sound in the past and will again in the future.

Liquefaction: If sediments (loose soils consisting of silt, sand, or gravel) are water-saturated, strong shaking can disrupt the grain-to-grain contacts, causing the sediment to lose its strength. Increased pressure on the water between the grains can sometimes produce small geyser-like eruptions of water and sediment called *sand blows*. Sediment in this condition is liquefied and behaves as a fluid. Buildings on such soils can sink and topple, and foundations can lose strength, resulting in severe damage or structural collapse. Pipes, tanks, and other structures that are buried in liquefied soils will float upwards to the surface.

Artificial fills, tidal flats, and stream sediments are often poorly consolidated and tend to have high liquefaction potential. For example, in the Darrington–Devils Mountain scenario, the liquefaction susceptibility of the land on either side of the Skagit and Nooksack rivers is rated moderate to high.

Landslides: Earthquake shaking may cause landslides on slopes, particularly where the ground is water-saturated or has been modified (for example, by the removal of stabilizing vegetation). Steeper slopes are most susceptible, but old, deep-seated landslides may be reactivated, even where gradients are as low as 15%. Catastrophic debris flows can move water-saturated materials rapidly and for long distances, mostly in mountainous regions. Underwater slides are also possible, such as around river deltas.

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Hazus Results for the Darrington–Devils Mountain Scenario

Hazus is a nationally applicable standardized methodology developed by FEMA to help planners estimate potential losses from earthquakes. Local, state, and regional officials can use such estimates to plan risk-reduction efforts and prepare for emergency response and recovery.

Hazus was used to estimate the losses that could result from a M7.1 scenario earthquake on the Darrington–Devils Mountain fault zone in southern Skagit and northern Snohomish counties. Such an event is expected to impact fifteen counties in Washington, with the most significant effects apparent in Skagit and Snohomish counties, followed by King, Island, and Whatcom.

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during the business day. Skagit County is expected to suffer the highest number of casualties; many of the injuries will be serious enough to require hospitalization. Numerous fatalities are likely if the event occurs during the afternoon or early evening.

Damage: The earthquake will damage buildings in all of the affected counties, but Skagit accounts for the greatest number. Nearly half of Skagit's building stock may be damaged; of these buildings, it is anticipated that more than 2,300 will be extensively damaged and approximately 750 completely damaged. After Skagit, the damage is greatest in Snohomish, Whatcom, and Island counties. Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total in this scenario.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Skagit County accounts for the largest portion of the capital stock loss estimate (over $677 million), followed by Snohomish (over $235 million), King (about $98.5 million), Island ($61.5 million), and Whatcom (about $46.5 million).

DARRINGTON–DEVILS MOUNTAIN SCENARIO	
End-to-end length of fault (kilometers)	50
Magnitude (M) of scenario earthquake	7.1
Number of counties impacted	15
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	652
Total number of buildings extensively damaged	4,864
Total number of buildings completely damaged	1,439
Income losses in millions	$391
Displaced households	1,971
People requiring shelter (individuals)	1,448
Capital stock losses in millions	$1,866
Debris total in millions of tons	0.65
Truckloads of debris (25 tons per truckload)	25,920
People without power (Day 1)	10,176
People without potable water (Day 1)	29,697

Table 1. Summary of significant losses in the M7.1 Darrington–Devils Mountain earthquake scenario. The counties most likely to be affected are Island, Jefferson, King, San Juan, Skagit, Snohomish, and Whatcom.

***Injury severity levels: 1—requires medical attention, but not hospitalization; 2—not life-threatening, but does require hospitalization; 3—hospitalization required; may be life-threatening if not treated promptly; 4—victims are killed by the earthquake**

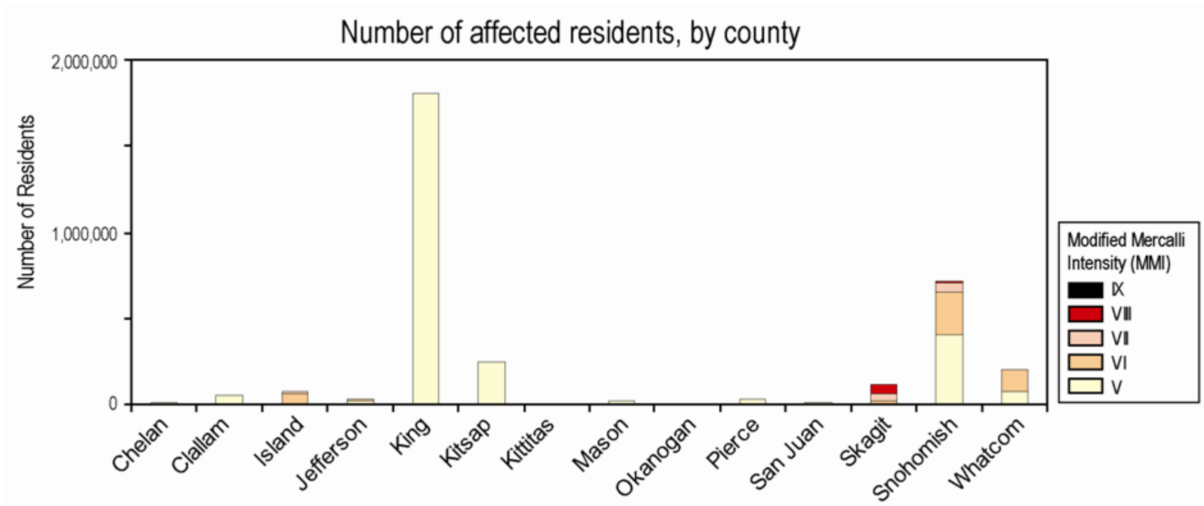
Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Skagit County (more than $175 million) and Snohomish County (about $33 million).

Impact on Households and Schools: The number of people without power or water is expected to be highest in Skagit County. This county also accounts for most of the displaced households and individuals in need of shelter. Schools in Skagit County will be only 51% functional on Day 1 after the earthquake.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from Skagit County (about 289,000 tons), with a significant portion from Snohomish, King, and Island counties (about 70,000 tons).

Estimates vs. Actual Damage: Although this M 7.1 earthquake scenario was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Other Tools: Community planners can also look at how a large earthquake may impact local resources and people's lives and livelihoods. The following graphs illustrate variations in such impacts: The first shows the levels of shaking that residents are likely to experience; the second shows possible impacts on different services and business sectors. Note that in King County, a greater number of residents will be exposed to less severe shaking, whereas Skagit and Snohomish counties, although less populated, will experience more intense ground motions.



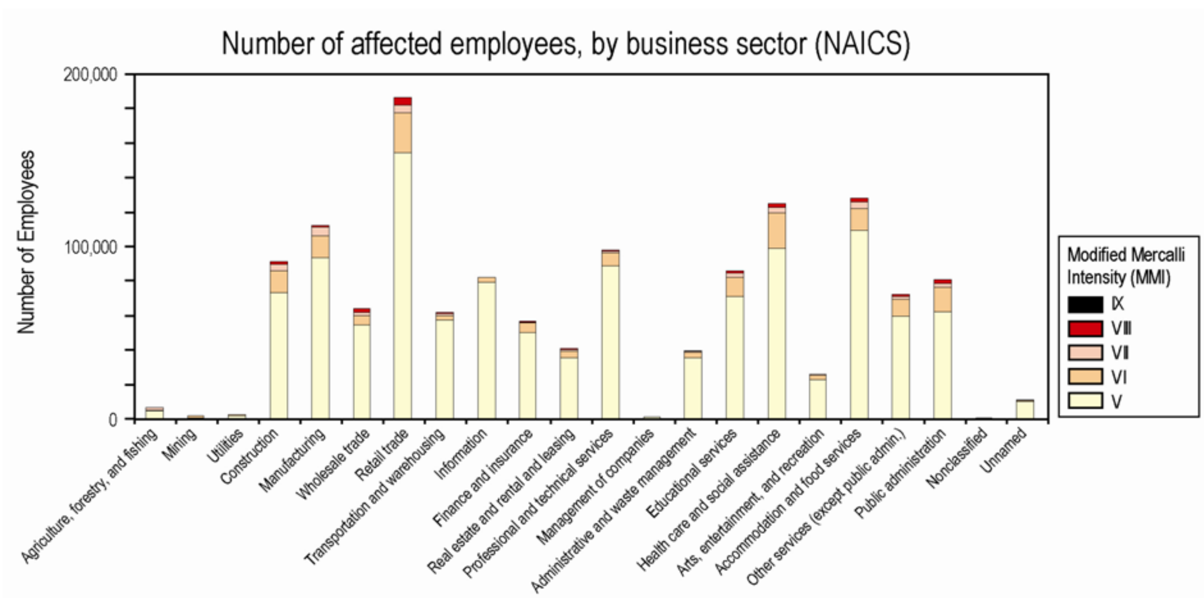


Figure 3. Number of residents and employees affected by the M7.1 earthquake in the Darrington–Devils Mountain scenario. Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of the shaking.

V. Rather Strong (PGA 3.9–9.2 *g*)	Felt outside by most. Dishes and windows may break. Large bells ring. Vibrations like large train passing close to house.
VI. Strong (PGA 9.2–18 *g*)	Felt by all; people walk unsteadily. Many frightened and run outdoors. Windows, dishes, glassware broken. Books fall off shelves. Some heavy furniture moved or overturned. Cases of fallen plaster. Damage slight.
VII. Very Strong (PGA 18–34 *g*)	Difficult to stand. Furniture broken. Damage negligible in buildings of good design & construction; slight-moderate in other well-built structures; considerable in poorly built/badly designed structures. Some chimneys broken.
VIII. Destructive (PGA 34–65 *g*)	Damage slight in specially designed structures; considerable in ordinary substantial buildings (partial collapse); great in poorly built structures. Fall of chimneys, factory stacks, columns, walls. Heavy furniture moved.
IX. Violent (PGA 65–124 *g*)	General panic; damage considerable in specially designed structures; well designed frame structures thrown out of plumb. Damage great in substantial buildings: partial collapse. Buildings shifted off foundations.