

DOGAMI Fact Sheet

Cascadia Earthquake Knowledge Points for Emergency Managers and the Public



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Do we anticipate a foreshock with this event?

It is possible. The recent Tōhoku Japan Mw 9.1 earthquake that occurred on 11 March 2011 was characterized by two foreshocks that occurred respectively 2 days (M_w 7.3) and 1 day (M_w 6.4) prior to the mainshock (Kiser and Ishii, 2013). However, recognizing these as foreshocks leading up to something larger remains the challenge.

What type of shaking should we expect?

It depends on many factors including distance to the fault rupture zone, the local geology below your feet (e.g., soft sediments on hard rock tend to amplify the shaking), whether you are inside or outside a building and the type of building (single versus multistorey). Ground shaking intensity may be qualitatively described using the Modified Mercalli Intensity Scale (MMI, Table 1). The MMI scale reflects increasing levels of intensity that range from shaking that is barely felt to extreme shaking leading to catastrophic destruction.

For a Cascadia event, ground shaking is expected to have a long duration (lasting ~3-5 minutes for the larger events) accompanied by severe shaking (MMI ~VIII – X, Table 1).

In contrast, a crustal earthquake is characterized by shaking that is short lived (~5-30 seconds, ~MMI 1 - VII); note a small earthquake will feel like a small sharp jolt followed by a few stronger sharp shakes that pass quickly.

Video footage ([click here](#)) from the Sendai Plain in Japan (nearest to the fault rupture) indicate that people were able to stand and move about. However, at the peak of the earthquake, standing became difficult in some places and people either sat down, got under desks, or got under other forms of protection. In Tokyo, 190 miles from the rupture zone, the shaking remained severe. Nevertheless, people can be seen ([click here](#)) evacuating from buildings at the peak of the earthquake shaking. Strong aftershocks persisted for many days after the main quake.

The Cascadia subduction zone (CSZ) is a 1000 km (620 mile) long “megathrust” fault that stretches from Cape Mendocino, California, to northern Vancouver Island in British Columbia, Canada. The fault zone lies at the interface of the Juan de Fuca plate, moving in an east-northeast direction at a rate of ~1.6 inches/year, and the slower moving North American plate, moving in a west-southwest direction at a rate of ~1 inch/year. At the plate interface, the Juan de Fuca plate dives (subducts) below the North American plate. Part of this region of subduction is locked, causing strain to accumulate as the CSZ builds energy toward the next earthquake. Due to the width of the locked region and length of fault zone, the CSZ has a history of producing very large (Moment magnitude (M_w) >8.7) earthquakes. Full-margin ruptures on the CSZ that trigger tsunamis are estimated to occur on average ~480 to 505 years; partial ruptures that affect southern Oregon and Northern California occur more frequently (~220 years). The last CSZ megathrust earthquake (estimated ~M_w 9.0) occurred on January 26th, 1700, at ~9 pm and produced a tsunami that inundated the Oregon coast. It is not a case of “if” the next great earthquake will occur, but “when”. This document provides answers to many frequently asked questions concerning a CSZ earthquake and tsunami.

What is the current estimated risk of a Cascadia earthquake and tsunami occurring in the next 50 years?

The probability of a Cascadia earthquake and tsunami occurring in the next 50 years are calculated at:

- 7–12 percent for a complete rupture (i.e., the entire 600-mile-long fault zone) (Goldfinger and others, 2012);
- 16–22 percent for a partial rupture that impacts the Oregon and northern California coast (Goldfinger and others, 2017); and,
- 37–43 percent for a partial rupture that would affect just the southern Oregon and northern California coast (Goldfinger and others, 2012).



Intensity Scale	Shaking	Effects on People	Effects on Objects	Effects on Buildings	Effects on Environment
I	Not felt	Felt only by very few under especially favorable conditions.			
II	Weak	Felt by a few at rest, especially on upper floors of buildings.	Delicately suspended objects may swing.		
III	Weak	Felt by some indoors, especially on upper floors of buildings. Vibrations similar to passing of a truck. Duration estimated.	Parked cars may rock slightly, hanging objects may swing appreciably.		
IV	Light	Felt indoors by many, outdoors by few, some awakened at night. Sensation like heavy truck striking building.	Dishes, windows, and doors disturbed, parked cars rock noticeably.	Walls creak, windows rattle.	
V	Moderate	Felt by nearly everyone, many awakened, frightens a few.	Pictures swing, some dishes and windows broken, unstable objects overturned.	Some cracked walls and windows.	Trees and bushes noticeably shaken.
VI	Strong	Felt by all, many frightened, some move unsteadily.	Many objects fall from shelves; some heavy furniture moved.	Damage slight, some fallen plaster, broken windows, and damaged chimneys.	Some fall of tree limbs and tops, isolated.
VII	Very strong	Frightens most; some lose balance.	Heavy furniture overturned.	Damage negligible in buildings of good design and construction; slight to moderate damage in well-built ordinary structures; considerable damage in poorly-built structures, weak chimneys broken at roofline, unbraced parapets fall.	Tree damage, rockfalls, landslides, and liquefaction more severe and widespread.
VIII	Severe	Many find it difficult to stand.	Fall of chimneys, factory stacks, columns, monuments, walls. Very heavy furniture moves conspicuously.	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures.	
IX	Violent	Some forcibly thrown to the ground.		Damage considerable in specially designed structures, well-designed frame structures thrown out of plumb. Damage is great in substantial buildings, with partial collapse. Buildings shifted off foundations.	
X	Extreme			Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.	

Table 1. The Modified Mercalli Intensity (MMI) scale provides a qualitative measure of earthquake shaking intensity (modified from U.S. Geological Survey, 20211; <https://www.usgs.gov/programs/earthquake-hazards/modified-mercalli-intensity-scale>)



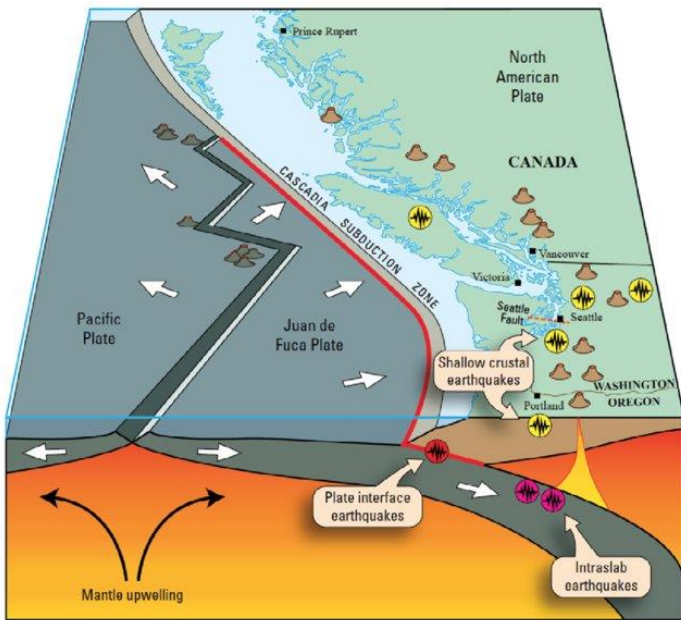


Figure 1. A three-dimensional diagram showing the types of earthquakes experienced in the Pacific Northwest. These include shallow crustal earthquakes, deep intraslab earthquakes, and offshore plate interface (megathrust) earthquakes. The oceanic Juan de Fuca Plate (shown in gray) subducts beneath the North American Plate (Given and others, 2018).

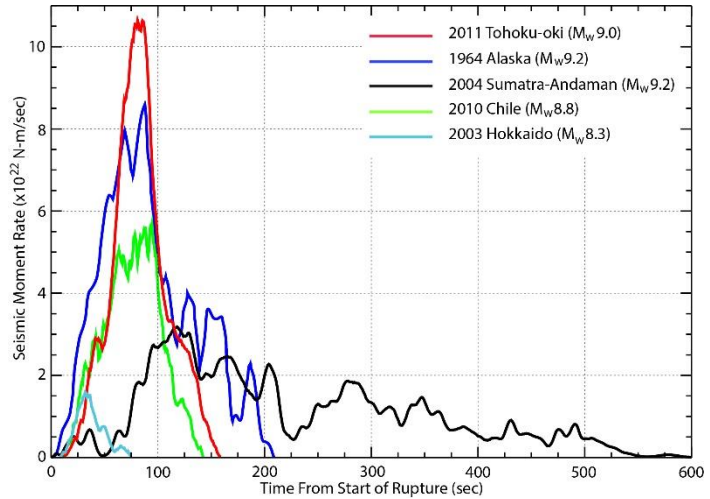


Figure 2. Rupture times for several great Earthquakes since the 1960s (Lay and Kanamori, 2011).

How many days do we anticipate after-shocks and to what magnitude?

The Tōhoku Japan Mw 9.1 earthquake is the best monitored event in history and those results provide a guide for what we might expect with Cascadia in a very large event. Data from the Japan Meteorological Agency (JMA) indicated some 2500 earthquakes occurred within the first 25 hours following the main earthquake (Kiser and Ishii, 2013), including 3 earthquakes that were Mw 7.0 or greater and 60 that were Mw 6.0 or greater; the median size of the aftershocks was ~ Mw 4.75 to 5.5 (~MMI III – VI, Table 1), with many, many smaller earthquakes. An example of the spatial distribution and size of earthquakes greater than a Mw 4 in the ten days following the 11 March 2011 great Japan earthquake is shown in Figure 3.

According to the USGS, the rate of aftershocks follows a few general rules:

- Large mainshocks (primary earthquake) trigger more aftershocks compared with small mainshocks.
- The rate of aftershocks decreases with time. In general, there are 10 times as many aftershocks on the first day as there are on the 10th day.
- The magnitudes of aftershocks do not necessarily get smaller with time, only their rate of occurrence changes.

What is the estimated number of minutes of shaking for the main shock?

Estimated rupture time is ~3-5 minutes but possibly shorter or longer, depending on the length of fault rupture; a full margin rupture is likely to be in the ~3-5 minute range, while a partial rupture (e.g. southern Oregon coast) is probably going to be >1 minute but <3 minutes.

Figure 2 indicates the duration of rupture time for great earthquakes that have occurred since 1964 (Lay and Kanamori, 2011). Note that the 1964 Alaska earthquake lasted ~4 minutes, the 2011 Tōhoku Japan earthquake lasted ~3 minutes, and the 2004 Sumatra earthquake lasted up to 10 minutes but was a ~20% longer fault rupture than likely for Cascadia.



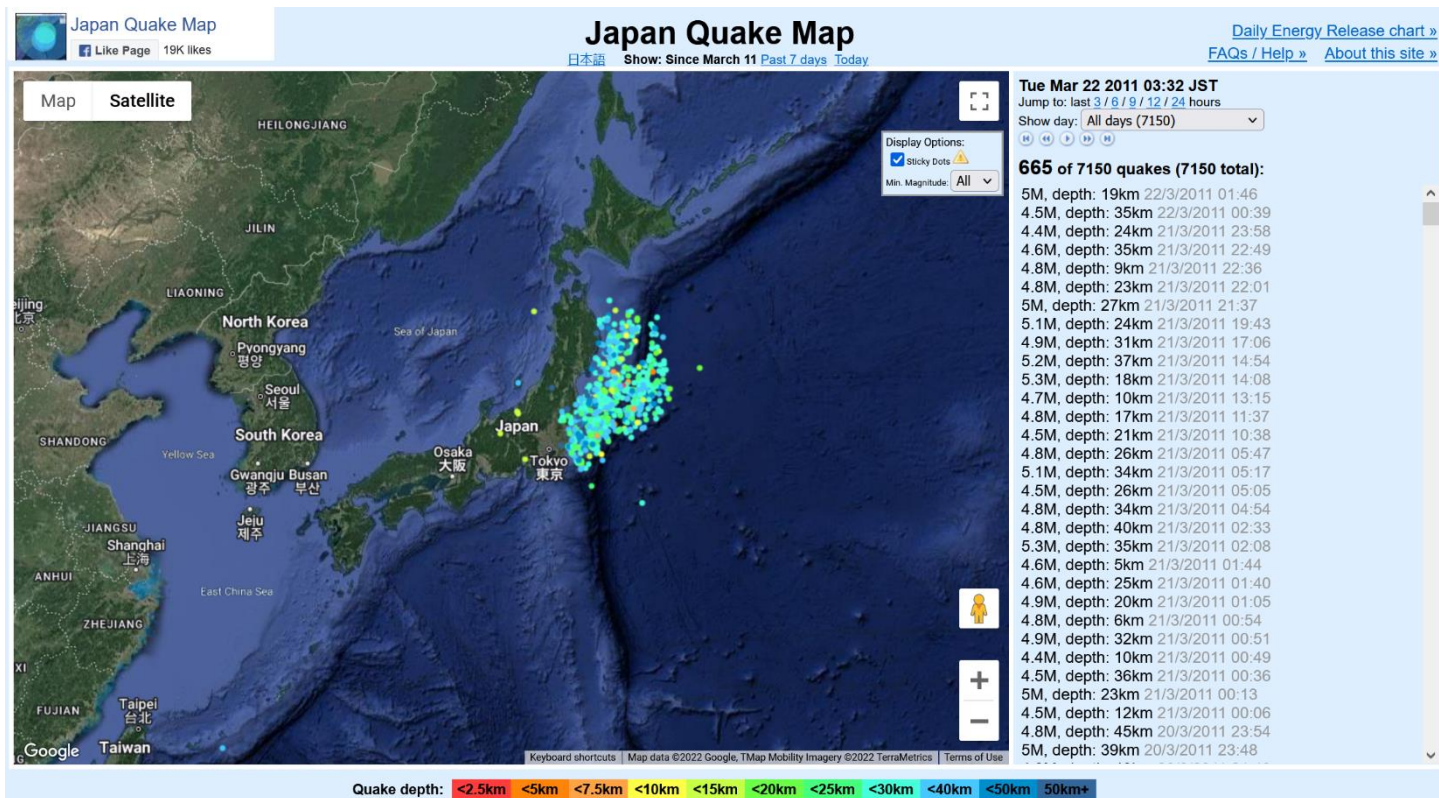


Figure 3. Earthquake aftershocks greater than ~MW 4 for the ten days immediately following the 11 March 2011 Tōhoku Japan MW 9.1 earthquake (<http://www.japanquakemap.com/>).

Aftershocks may be felt years after the mainshock. For example, a recent Mw 7.3 earthquake on 16 March 2022 occurred near the Tōhoku 2011 epicenter may or may not have been an aftershock ([click here](#)). A tsunami advisory was issued by JMA March 2022 event indicating that waves of up to 3 ft could occur, but the actual waves measured were < 1 ft.

Additional information concerning aftershocks may be found on the US Geological Survey earthquake website ([click here](#)).

What is the expected speed of the incoming tsunami surge?

Open ocean approximately 700 to 800 kilometers per hour (kph, ~450 to 500 miles per hour (mph)). Once it reaches the coast, the speed of the tsunami slows significantly to ~55 kph (35 mph) due to frictional effects. To compensate for the slowing down of the wave, the tsunami wave increases in height and inundates the coast. The speed of the tsunami continues to slow as the tsunami waves travel inland and up estuaries, eventually running out of energy.

How many hours/days do we anticipate tsunami surges to continue after the main shock?

Dangerous tsunami waves will be concentrated within the first 12 hours after the mainshock. Along the open coast, the first wave arrival will be the largest surge. In estuaries, later arriving surges could produce bigger waves and greater inundation due to interactions with different tidal stages. The general consensus is to remain out of the tsunami zone for at least 12 hours after the earthquake. Expect dangerous currents to persist in the estuaries for much longer periods of time.

How long will the tsunami surge (water volume) stay within the inundation zone?

The tsunami will reach the beach in about 10 - 20 minutes following the mainshock. Simulated tsunami wave arrival times for different parts of the Oregon coast have been developed by DOGAMI ([click here](#)). Video animations of a maximum considered Cascadia tsunami affecting different parts of the Oregon coast may be found on the Oregon tsunami clearinghouse website ([click here](#)).



The first tsunami wave fully inundates the coastal strip in ~34 minutes. Subsequent tsunami waves will ebb and flood the coast for up to 12 hours after the mainshock. Water is likely to pond in low lying areas for hours or even days after the event. For example, some parts of the coast (e.g. Seaside-Gearhart, Neskowin and Rockaway) will likely retain a “lake” of water and debris.

Will the aftershocks trigger another local tsunami?

It is possible though unlikely and would depend on several factors. An aftershock would need to be a specific type of earthquake (thrust event out in the ocean) and of a sufficient magnitude (> M_w 7) to uplift the water column. Note that in the 11 March 2011 Japan earthquake, there were three aftershocks > M_w 7 that did produce some small tsunamis.

Part of the uncertainty here is also dependent on whether the entire subduction zone ruptures or not. If it is a partial rupture, then there is the possibility of another major earthquake (not an aftershock) on the subduction zone. Unfortunately, there is little data to estimate how long it might take for such an event to occur.

What is the current estimation of coastal subsidence?

The best available estimates from modeling are from the work of Witter and others (2011). Based on their simulations (Figure 4) the central Oregon coast could experience coastal subsidence that ranges from 3 to 6 feet (L - XXL); the M1 scenario yields subsidence of ~2 ft. Note, the coastal subsidence response in these models is guided by geologic data taken from marsh cores that provide only minimum estimates in most cases. Uncertainty in these geologic data are factored into the models of coastal subsidence developed by DOGAMI.

During the 2011 Tōhoku Japan M_w 9.1 earthquake, measured coastal subsidence reached a maximum of ~3.9 ft on the Sendai Plain (Nishimura, 2014).

Post-earthquake uplift modeled for the Sendai Plains suggest that the land is expected to rise relative to mean sea level by ~1.6 ft 100 years after the earthquake and ~2.5 ft by 200 years (Sasajima and others, 2019).

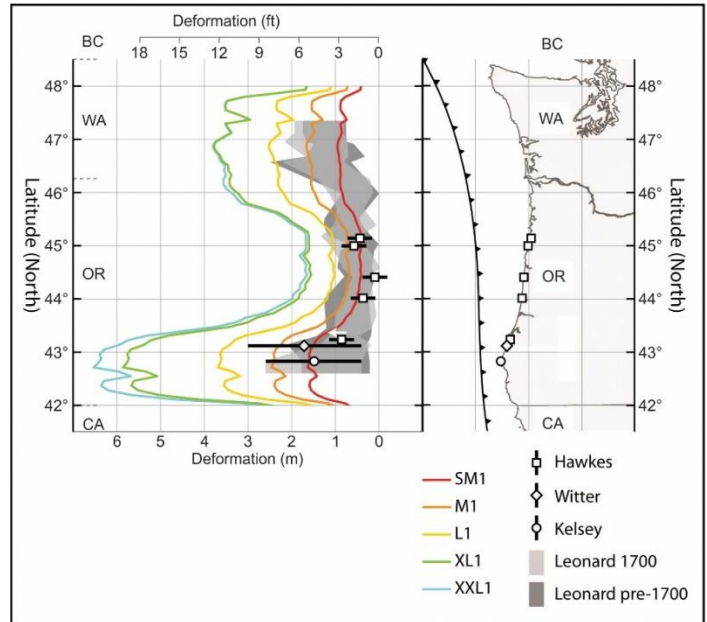
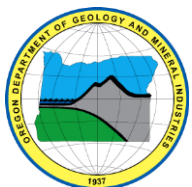


Figure 4. An along-coast depiction of modeled (colored lines) and measured (gray shading) coastal subsidence produced by CSZ earthquakes. Lowering of the ground elevation relative to a vertical datum such as mean sea level is referred to as subsidence and will occur along the coast, while inland areas will be uplifted; the combined subsidence/uplift process is referred to as the coseismic response. Modeled scenarios SM to XXL are shown in rainbow colors and demonstrate the wide range of values that can be experienced depending on location and size of the earthquake. Measured coseismic responses from historic Cascadia earthquakes are shown as grey shaded regions. These estimates were derived from coastal marshes and estuaries and reflect minimum measurements of coastal subsidence.

Will the estuaries and rivers have a higher water level after the tsunami and if so for how long?

The coast is likely to be lowered by 3 – 6 ft relative to mean sea level (or some comparable vertical datum e.g. NAVD88), which means water levels will be vastly different after the event and throughout the region. These changes could be expected to last many years to even decades. It is also true that the subduction zone will immediately begin accumulating strain again after the event as it builds to the next great earthquake, which means the coast will begin to rise again relative to the ocean (on the order of millimeters per year).



How do we anticipate the ocean floor and estuaries will change?

The earthquake shaking will result in coastal subsidence of about 1 – 2 m (~3 - 6 ft), collapse of sidewalls along navigation channels, lateral spreading of estuary and river channels, infilling of channels with debris and sediment, tsunami current erosion, and damage to jetties. All of these changes would significantly alter the hydrodynamics of estuaries. If the EQ is greater than a medium (M) event (i.e. an L or XXL) as defined from the modeling by DOGAMI, we could expect to see even greater coastal subsidence and tsunami effects.

The bulk of the expected impacts would occur because of the mainshock. However, we may see further destabilization of banks and channels in some locations as a result of aftershocks.

With the lowering of the coast, we can expect to see very significant coastal erosion as the beaches, dunes and bluffs respond to an entirely different mean water level. This will likely last for years to decades as the coastline strives to reach a new equilibrium.

What happens if you are on the beach?

People should evacuate from beach areas immediately they feel an earthquake, either by EEW on their cell phones or the actual start of felt shaking. If they do not, they could find themselves stuck as the tsunami arrives.

Because of the predominance of Earthquake Early Warning (EEW) instrumentation on land, does EEW provide the most benefit for warning about on-shore or crustal earthquake faults, versus the Cascadia subduction zone?

The overwhelming majority of EEW instruments are located on land. Instrumentation of the CSZ will likely expand rapidly in the coming years and will almost certainly improve EEW. For example, the USGS recently placed geophysical instruments near the CSZ trench to document tectonic movement. However, at the end of the day such data may still only provide a few seconds warning. While this may not sound like much, especially compared to the EEW for crustal earthquakes in southern California that may receive warning times that range from seconds to a few 10s of seconds, any warning is still extremely valuable for triggering automated actions such as slowing down trains, disconnecting gas mains, shutting down key computer systems, etc.

On an individual level, EEW may provide enough time to take a protective action such as Drop, Cover and Hold on. Remember that a CSZ earthquake will essentially generate its own tsunami warning, regardless of the EEW. If earthquake shaking is very long (lasting minutes, see Figure 2), that is all the warning you need that a tsunami has probably been generated and that you must immediately evacuate from the tsunami zone and head to high ground.

Wood frame buildings, the norm for buildings in Oregon, are generally thought to perform fairly well in earthquakes. Is this true and what might we expect?

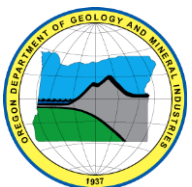
The answer to this is that it depends. The aftermath of crustal earthquakes in the United States has demonstrated repeatedly that wood frame buildings generally perform well during earthquakes. This is because they cope better against high frequency seismic waves; flexing instead of breaking like more brittle construction materials such as brick or concrete. However, these responses are predicated on age of construction; in Oregon, construction standards changed dramatically after ~1990. Other factors that influence building response during an earthquake are building heights and the underlying geology (Figure 5).

Prior to the 1950s, United States residential buildings were not designed with earthquakes in mind (Figure 5). These buildings will not perform that well in an earthquake.

Buildings built in the 1950s were found to perform quite well (see slight dip above) because their overall layout (e.g. single story) was simpler than those built after the 1960s. Earthquake engineering design did not really begin to become fully integrated into building codes until ~2000, such that structures built post-2000 were found to perform relatively well.

In general, buildings built prior to 2000 remain vulnerable and will not perform as well as those built post-2000. Furthermore, single story structures will generally perform better than multi-story buildings. Vulnerability of older buildings will continue to deteriorate over time as the natural material deteriorates with age.

Risk assessments undertaken by DOGAMI using Hazus modeling include factors such as building age, construction material, and building height to assess the likelihood of a building surviving an earthquake or being damaged.



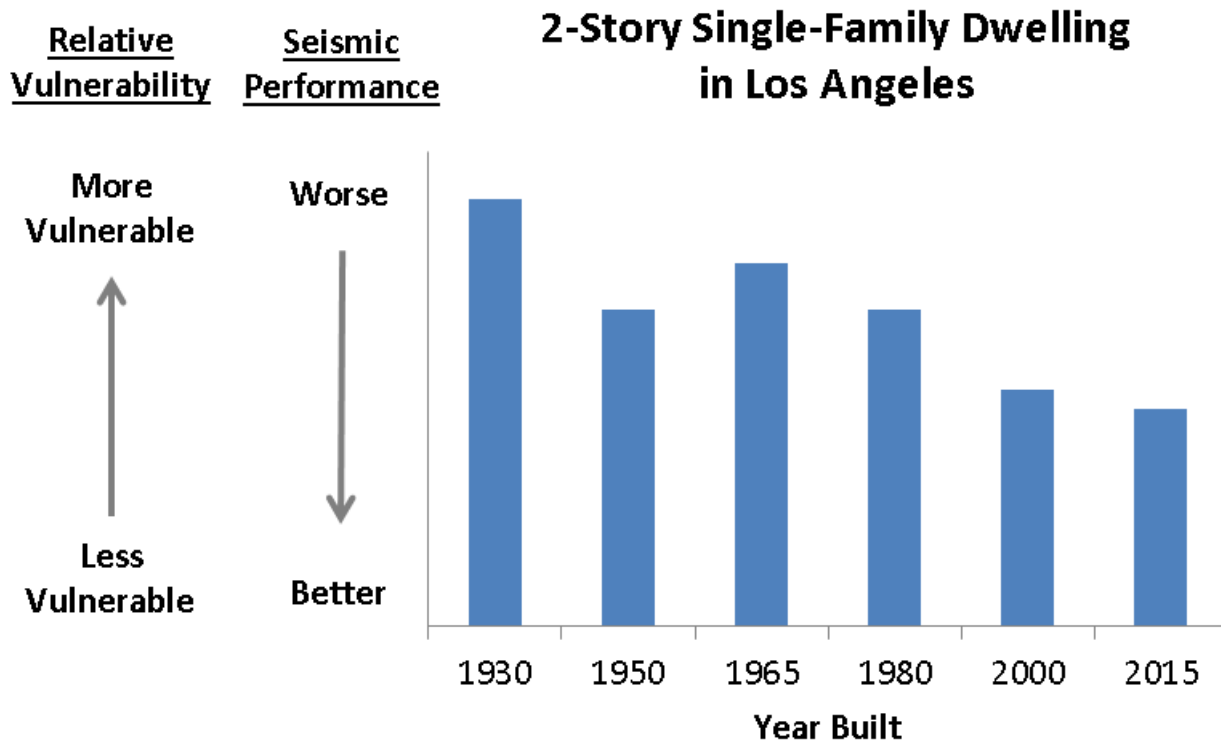


Figure 5. The relative vulnerability to EQ damage, by year built, of two-story wood frame single-family dwellings in Los Angeles (source: <https://www.air-worldwide.com/publications/air-currents/2017/U-S--Earthquake-Model-Update-Enhances-View-of-Wood-Frame-Vulnerability/>)



Glossary

Aftershock: Aftershocks are earthquakes that follow the largest shock of an earthquake sequence. They are smaller than the mainshock and within 1-2 rupture lengths distance from the mainshock. Aftershocks can continue over a period of weeks, months, or years. In general, the larger the mainshock, the larger and more numerous the aftershocks, and the longer they will continue.

Cascadia subduction zone: A 1000 km (620 mi) long fault zone in which the Juan de Fuca plate is being subducted beneath the North American Plate. Geologic data indicates that this fault zone has generated large magnitude earthquakes over the past 10,000 years that were accompanied by catastrophic tsunamis.

Crustal earthquake: These are shallow earthquakes, with depths no greater than about 35 km (~22 mi), and are caused by the rupture of faults within the North American Plate. The sizes of earthquakes are related to how big their ruptures are, and the biggest crustal faults in our region could produce earthquakes with magnitudes as large as M_w 7.5. Crustal earthquakes can and do occur throughout the Pacific Northwest, though they occur more frequently where the crust is deforming the fastest.

Earthquake Early Warning (EEW): EEW systems were first developed in Mexico and Japan and have now been rolled out along the United States West Coast. The purpose of EEW is to seek to detect the initial seismic waves at the beginning of an earthquake and notify users that shaking is imminent at their location using smartphone technology.

Foreshock: Foreshocks are relatively smaller earthquakes that precede the largest earthquake in a series, which is termed the mainshock. Not all mainshocks have foreshocks.

Intraslab earthquake: These are earthquakes that occur within tectonic plates.

Mainshock: The mainshock is the largest earthquake in a sequence, sometimes preceded by one or more foreshocks, and almost always followed by many aftershocks.

Mean sea level (MSL): The arithmetic mean of hourly sea level heights observed over a 19-year period (the National Tidal Datum Epoch). Shorter series are specified in the name e.g., monthly mean sea level or yearly mean sea level.

Moment Magnitude (MW): Is a function of the seismic moment and is a measure of the size of an earthquake based on the area of fault rupture, the average amount of slip, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting.

NAVD88: the North American Vertical Datum of 1988

Rupture: an earthquake rupture is the extent of slip that occurs during an earthquake in the Earth's crust. The Cascadia subduction zone is a 1000 km (620 mi) long fault, that is presently locked allowing strain to build toward the next great earthquake.

Subduction earthquake: The subduction zone is the place where two lithospheric plates come together, one riding over the other. Most volcanoes on land occur parallel to and inland from the boundary between the two plates. It is a zone in which large earthquakes occur due to locking of the plates, allowing strain to build that is eventually released during an earthquake.

Subsidence: This is the lowering of the ground surface due to an earthquake

Thrust faulting: These are inclined fractures where the blocks have mostly shifted vertically. If the rock mass above an inclined fault moves down, the fault is termed normal, whereas if the rock above the fault moves up, the fault is termed reverse. A thrust fault is a reverse fault with a dip of 45 degrees or less. Upward movement of a thrust fault below the ocean could produce a tsunami.

A full Earthquake Glossary, compiled by USGS, can be found at: <https://earthquake.usgs.gov/learn/glossary/>



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Video Links:

- <https://www.youtube.com/watch?v=mk68bZ701s0>
- <https://www.youtube.com/watch?v=9nTlgtf7TME>
- <https://www.oregongeology.org/tsuclearinghouse/pubs-videos.htm>

