4-9: Earthquake

Hazard Impacts	Probability	Potential Impact					Score*:
		Infrastructure	Life	Economy	Environment	**Average:**	
Earthquake	2	3	3	3	2	2.75	5.5

*Score = Probability x Average Potential Impact

According to the USGS, an earthquake occurs when two blocks of the Earth suddenly slip past one another along what is called a fault or fault plane. As the two blocks slide, stored energy is released producing radiating seismic waves that result in an earthquake. The location below the Earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the Earth is called the epicenter.

Earthquakes in the northeastern United States generally have deep foci (>10 km) and are considered to be intraplate. Earthquakes that occur within an intraplate seismic zone are not typically expressed on the ground surface and are, therefore, more difficult to model[1]. Although there are numerous faults exposed at the ground surface in the northeastern United States, there is no evidence for significant motion along these faults.

A computer earthquake damage simulation (HAZUS program) conducted by the Vermont State Geologist's Office in 2012[2] suggests that there is little earthquake risk in Vermont at 100-year and 250-year recurrence intervals; however, there is a potential risk at the 500-year recurrence level. A Report on The Seismic Vulnerability of the State of Vermont[3] postulated six 500-year "strong" earthquake epicenters in the Northeast that could be expected to cause damage in Vermont are located at Middlebury (5.7 magnitude), Swanton (5.7 magnitude), Montreal, Quebec (6.8 magnitude), Goodnow, New York (6.6 magnitude), Tamsworth, New Hampshire (6.2 magnitude), and Charlevoix, Quebec, Canada (6.6 magnitude). Using these epicenters and magnitudes, further HAZUS runs confirmed that five of these earthquakes (absent Charlevoix) could cause ground shaking in certain parts of Vermont sufficient to result in millions of dollars in damage.

Five of these six possible 500-year earthquakes have moment magnitudes and epicenters close enough to Vermont to cause significant damage. These five earthquakes have predicted peak ground accelerations (PGAs), used to measure the amplitude of the largest acceleration at a given site during an earthquake, greater than 0.1g and would cause widespread damage resulting in tens to hundreds of millions of dollars in structural and economic losses and undetermined casualties. The Swanton and Middlebury earthquakes were estimated to have PGAs of 0.4g and total losses exceeding $300 million dollars each (HAZUS-MH projections). In addition to the five postulated 500-year earthquakes that would affect Vermont, the 2002 occurrence of a 5.3 magnitude earthquake near Plattsburgh, New York, indicates that this epicenter should also be considered.

1 Hubenthal M, Stein S, & Taber J. 2011. A Big Squeeze: Examining and Modeling Causes of Intraplate Earthquakes in the Earth Science Classroom. The Earth Scientist, 27 (1), 33-39.
2 https://anrweb.vt.gov/PubDocs/DEC/GEO/HazDocs/HAZUS_VTScenarios_NE.pdf
3 http://dec.vermont.gov/sites/dec/files/geo/HazDocs/Ebell_1995.pdf

Middlebury Scenario:

- Building Damage: HAZUS-MH estimates that over 3,600 buildings will receive at least moderate damage. Of these, 38 buildings will be completely destroyed. This is over 2% of the total number of buildings in the State. For essential facilities, HAZUS-MH also estimates that on the day of the earthquake, 98% of hospital beds will be available and by 30 days, 100% will be operational. One school will receive moderate damage. It is predicted that over 262 families will be displaced from their homes and 62 will need temporary shelter.
- Transportation and Utility Systems: HAZUS-MH estimates minimal disruption of the transportation and utility systems. However, over 2,000 households are expected to be without electrical power for up to 3 days.
- Casualties: The model predicts 69 casualties requiring medical attention, 12 needing hospitalization, and 2 killed by the earthquake.
- Economic Loss: Direct building losses are estimated at greater than $308 million; 10% of these losses are due to business interruption. HAZUS-MH estimates that damage to transportation systems will be $34 million. Approximately $0.21 million would be needed to repair damaged communication systems.
- Government Buildings: 14 structures are predicted to receive slight damage, 6 will receive moderate damage, and 1 will be extensive.

Montreal Scenario:

- Building Damage: HAZUS-MH estimates that over 3,400 buildings will receive at least moderate damage. This is over 2% of the total buildings in the State. Of these, 23 buildings will be completely destroyed. For essential facilities, HAZUS-MH also estimates that on the day of the earthquake, 95% of hospital beds will be available and by 30 days, 100% will be operational. It is predicted that over 229 families will be displaced from their homes and 56 will need temporary shelter.
- Transportation and Utility Systems: HAZUS-MH estimates no disruption of the transportation and utility systems and no households are expected to be without electrical power.
- Casualties: The model predicts up to 70 casualties requiring medical attention, 12 needing hospitalization, and 2 killed by the earthquake.
- Economic Loss: Direct building losses are estimated at greater than $198 million; 17% of these losses are due to business interruption. HAZUS-MH estimates that damage to transportation systems will be $18 million. Approximately $0.03 million would be needed to repair damaged communication systems.
- Government Buildings: 15 structures are predicted to receive slight damage, 7 moderate damage, and 1 extensive.
- Developed in the early 1900s, the Modified Mercalli Intensity (MMI) scale assesses an earthquake's intensity qualitatively, based on the effects that are experienced on the ground. The lower the MMI score, the more likely the earthquake was only felt by people near the epicenter. As the intensity score increases, damage to structures are observed.

Table 37: Modified Mercalli Intensity (MMI) Scale			
Intensity	**Shaking**	**Description/Damage**	**Richter**
I	**Not felt**	Not felt except by a very few under especially favorable conditions.	1.0-3.0
II	**Weak**	Not felt except by a very few under especially favorable conditions.	3.0-3.9
III	**Weak**	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.	
IV	**Light**	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.	4.0-4.9
V	**Moderate**	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.	
VI	**Strong**	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.	5.0-5.9
VII	**Very Strong**	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.	
VIII	**Severe**	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.	6.0 and higher
IX	**Violent**	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage 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.	
XI	**Extreme+**	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.	
XII	**Extreme++**	Damage total. Lines of sight and level are distorted. Objects thrown into the air.	

Source: https://earthquake.usgs.gov/learn/topics/mag_vs_int.php

Earthquake History

Vermont is classified as an area with low to moderate seismic activity. Since 1900, Vermont has only experienced three earthquakes registering 2.5 or greater on the Richter Scale. The two strongest recorded earthquakes measured in Vermont were of a magnitude 4.1 on the Richter Scale. One was centered in Swanton and occurred on July 6, 1943, and the second occurred in 1962 in Middlebury. The 1962 earthquake was felt throughout New England and resulted in broken windows and cracked plaster, while the Swanton earthquake caused little damage. It is likely that small earthquakes will continue to occur in the coming years.

In addition, earthquakes centered outside the State have been felt in Vermont. Twin earthquakes of 5.5 occurred in New Hampshire in 1940. In 1988, an earthquake with a magnitude 6.2 on the Richter Scale took place in Saguenay, Quebec and caused shaking in the northern two-thirds of Vermont (Ebel, et. al. 1995).

On April 20, 2002, a 5.1 magnitude event in Plattsburgh caused shaking in Vermont with damage near the epicenter in New York. In the last five years, there have been only five earthquakes in the New England/ Northern New York and Southeast Ontario/Southwest Quebec region that recorded 3.0 magnitude or higher on the Richter Scale: 7/4/14 Saint-Andre-Avellin, Quebec, magnitude 3.0; 1/12/15 Wauregan, Connecticut, magnitude 3.3; 7/15/15, Hawkesbury, Canada, magnitude 3.3; 11/18/15, Cornwall, Canada, magnitude 3.2; 10/19/17, Mont-Tremblant, Canada, magnitude 3.1.

Earthquake Trends & Vulnerability

Unlike some natural hazards, it is not currently possible to predict when or where an earthquake may occur in New England. Due to Vermont's intraplate location, earthquakes in this region are not as well understood as those locations that lie along a plate boundary. Given this inability to predict the location and extent of the next earthquake, coupled with our history of relatively minor and very infrequent events, the Steering Committee considered the probability of a plausibly significant event to occur once every one hundred years with moderate impacts to the State's infrastructure, economy and human life.

Though New England sits intraplate, there are areas of the region that record higher rates of peak ground accelerations. The Adirondack region of New York and the geographical region of Canada between Ottawa and Montreal have higher PGAs, which have had recorded earthquakes that caused ground movement in Vermont. Because of this PGA distribution, the northwest region is more vulnerable to earthquake than the rest of the State (Figure 57). Further, as the Vermont Geological Survey continues to better understand the distribution of the State's landslides (see: Landslides), it is currently understood that the northwest region is also more prone to landslide hazards. As earthquakes often cause landslides, these two hazards can have a compounding effect and exacerbate impacts.

Many earthquake events have been recorded outside of the Vermont boundary, but residents can occasionally feel ground movement and have experienced minor non-structural impacts from these events. The USGS has a Did You Feel It? (DYFI) reporting tool that allows users to submit reports of ground movement, which then helps seismologists better understand the extent and impacts of ground movement[4] (Figure 58). This tool can then be used to research past events and increase awareness of a region's vulnerability to earthquake effects, allowing people to then develop mitigation actions accordingly.

Finally, with the expansion of the Vermont Gas pipeline in mid-2017, an additional 41 miles of underground piping was constructed between Colchester and Middlebury. This pipeline, which now spans from the Quebec-Vermont border to Middlebury, is critical infrastructure potentially vulnerable to ground shaking, especially when considering its location along the northwestern and west-central region of the State.

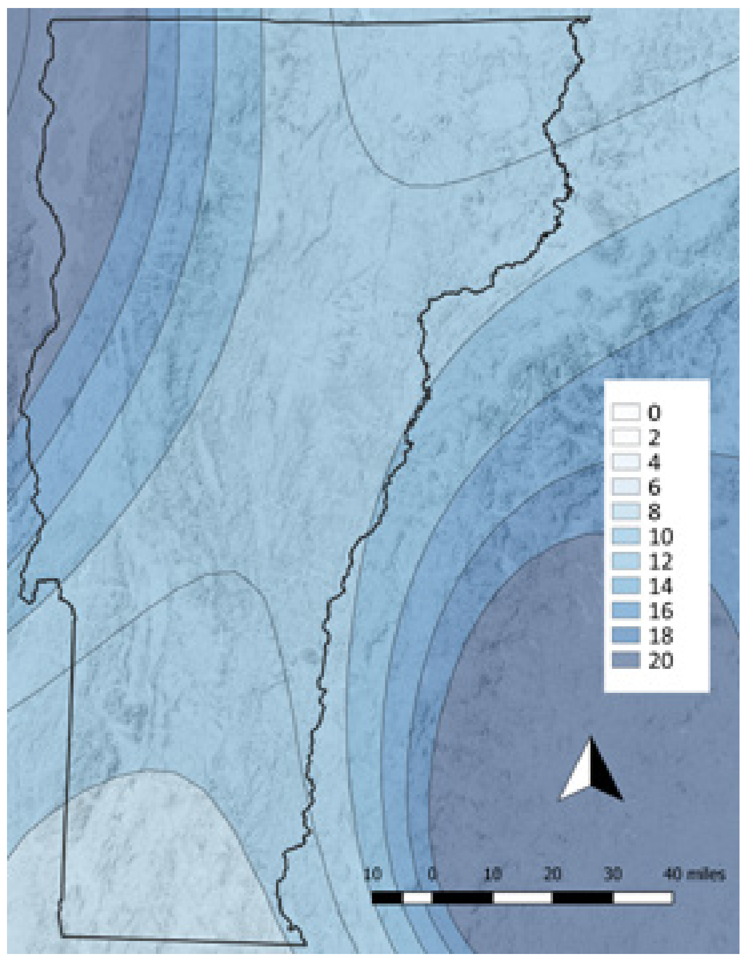

Figure 57: Peak acceleration expressed as a percent of gravity (%g)
Source: https://earthquake.usgs.gov/hazards/hazmaps/conterminous/

4 https://earthquake.usgs.gov/data/dyfi/summary-maps.php

Earthquake Mitigation

Given the low probability of a significant event, earthquake mitigation is often not a high priority at the State, regional or local level; however, as it is well understood by the Steering Committee that a significant event could have substantial impacts to infrastructure and human life, several mitigation actions have been developed as part of the Plan update process. This Plan identifies two actions that need to be taken to better assess the State's vulnerability to seismic hazards, which include conducting seismic analyses of a) bridges using the University of Vermont's seismic vulnerability ranking system; and b) critical facilities and historic sites using HAZUS and ROVER (see: Mitigation Strategy). These analyses will better inform subject matter experts of the State's vulnerability to earthquakes and provide data necessary for mitigation project development.

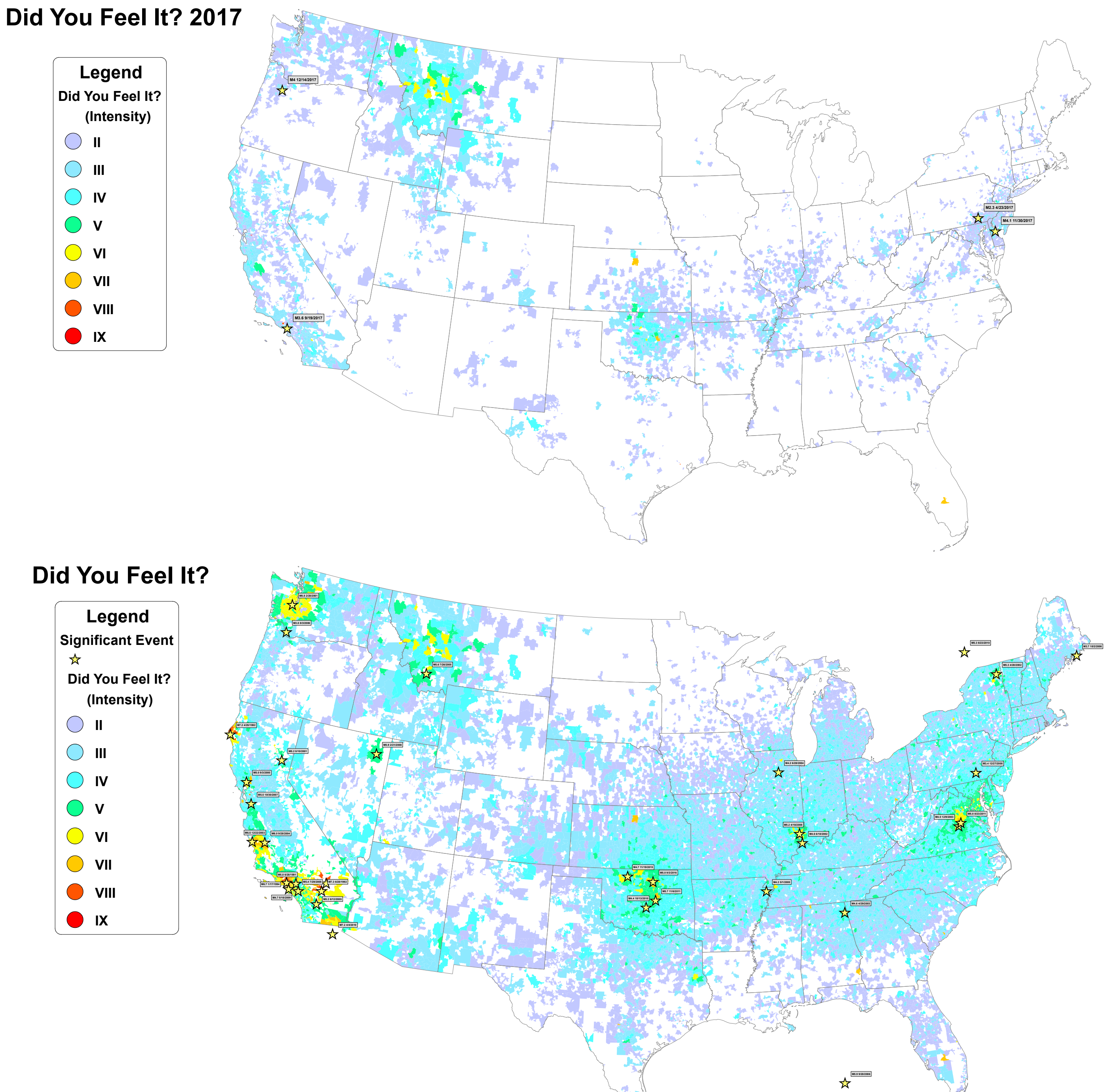

Figure 58: U.S. Earthquake Responses in 2017 (top) and Cumulative (1991-2017)
Source: https://earthquake.usgs.gov/data/dyfi/summary-maps.php