**4-12: Earthquakes**

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[[1]](#footnote-2).

Earthquakes in the northeastern United States generally have deep foci (>10 km) and are considered to be intraplate; that is, they occur within plates rather than along current tectonic plate boundaries. Earthquakes that occur within an intraplate seismic zone are not typically expressed on the ground surface and are, therefore, more difficult to model[[2]](#footnote-3). Although there are numerous faults exposed at the ground surface in the northeastern United States, most are ancient and there is no evidence for significant ongoing motion along these faults.

A computer earthquake damage simulation (HAZUS program) conducted by the Vermont State Geologist’s Office in 2012[[3]](#footnote-4) 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[[4]](#footnote-5) 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 these earthquakes (absent Charlevoix) have moment magnitudes and epicenters close enough to Vermont to result in 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.

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.

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| **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://www.usgs.gov/programs/earthquake-hazards/modified-mercalli-intensity-scale*](https://www.usgs.gov/programs/earthquake-hazards/modified-mercalli-intensity-scale) |

**Location**

Earthquakes can occur anywhere in the State of Vermont. Please see earthquake history and trends for more details on location.

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

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 in every one hundred years with negligible impacts to the State’s built environment, people, economy, and natural environment.

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 relatively 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[[5]](#footnote-6) (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.

Vulnerability

People

The impacts that earthquakes can have in Vermont tend to be minimal, relative to other regions of the country that rest on tectonic plate boundaries. With few earthquakes occurring with a magnitude of 2.5 or greater over the past century. Population density in Vermont is higher now than ever before, potentially increasing the risk for human lives near to impacted areas. People who live in both urban and rural areas can be at risk due to structural damage in buildings that can trap or harm residents. Earthquake-triggered events such as landslides can cut off access to aid in rural areas, preventing emergency services from reaching remote areas. People with low mobility or that are hospitalized can experience additional risk during a seismic event. A significant earthquake may cause many simultaneous emergency situations and thus may severely strain the ability of emergency service providers to respond adequately to all the accident sites[[6]](#footnote-7). Should an event be strong enough to damage dams or cause dam failure, thousands of people could be put at risk downstream. For example, failure of the Waterbury Dam could put 10,000 people in harm’s way, and up to 800 people may perish (largely in Waterbury), and 1,200 buildings would be impacted[[7]](#footnote-8).

Built Environment

Seismic impacts on the built environment are likely going to be the most pronounced out of the vulnerability categories. Earthquakes can cause structural damage to buildings that are not properly built or rated to withstand seismic events. Enough movement can cause cracking and glass shattering in ill-prepared structures. Ground movement can cause the cracking and breaking of roadways, resulting in obstacles to travel. Utilities such as electricity, water, sewage, and gas can all be impacted through ground shaking, especially if these are subsurface utilities. The Vermont Gas pipeline (aka the TransCanada Pipeline), which runs for more than 750 miles from Canada through Highgate, VT to Middlebury with underground transmission and distribution lines[[8]](#footnote-9), represents critical infrastructure potentially vulnerable to ground shaking, especially when considering its location along the northwestern and west-central region of the State. Cracks in this pipeline can cause gas leaks that lead to untold environmental damage in conjunction with the structural damage to the pipeline. According to the National Earthquake Hazard Reduction Program of the U.S. Geological Survey, there is approximately a 10% chance that parts of Vermont will experience shaking of at least 8 to 10% of gravity in any given 50-year period. This level of shaking is sufficient to cause property damage. There is roughly a 2% chance that parts of Vermont will experience shaking of at least 18-20% of gravity in any given 50-year period. Such shaking is sufficient to cause considerable damage to property. These estimates are for sites directly underlain by solid rock. Sites with thick soils may experience greater shaking due to amplification of seismic waves. Also, the height and method of construction of a building have a great influence on how it will behave in a quake[[9]](#footnote-10).

Natural Environment

The impacts of earthquakes on the natural landscape are largely dependent on the magnitude of the event and the local geology of the region. Given that Vermont is situated on an intraplate zone, there are no major fault lines nearby that pose significant hazards. Most impacts earthquakes can have on the natural environment are caused by ground movement. Ground resonance, surface faulting, and ground failure can all occur as a result of a seismic event. The thickness and strength of soils has a great influence on how strongly an earthquake is felt. Thick deposits of weak sediments can amplify seismic waves and make the quake feel stronger than on sites directly underlain by solid rock. Also, some types of saturated soils may liquefy and deform under the shaking of an earthquake. Vermont’s varied topography can trigger collateral mass wasting hazards where unconsolidated materials rest on unstable slopes. Under enough stress, earthquakes can cause failures in dams that can threaten thousands who live downstream of Vermont’s hydroelectric and flood control dams. For example, should the Waterbury Dam fail flooding will occur and impact the landscape from Middlesex to Burlington[[10]](#footnote-11). Flooding could damage crops and important forested sites within the path of the floodwaters. Many agricultural operations take place on the fertile soils of Vermont floodplains, which can put those fields at risk. Typically, farmers are adapted to seasonal flooding that replenishes soil nutrients, but unexpected flooding can cause a loss of agricultural goods.

Economy

Earthquakes can have significant economic impacts throughout the state. Impacting critical infrastructure including roadways, dams, utilities, pipelines, and buildings. Road access can be hampered by cracking caused by ground shifting limiting mobility and requiring maintenance to repair. Dams, aside from causing widespread destruction in the event of their failure, are important sources of recreational and economic activity. Should a dam be damaged, its ability to generate electricity for surrounding homes and businesses can be infringed[[11]](#footnote-12). Urban centers often have their utility lines and water pipes buried to decrease obstruction and to regulate temperatures in the winter to prevent freezing. Ground movement can damage or sever these connections, stopping the flow of critical utilities while also requiring urgent repairs. Strategic gas and oil pipelines could also be at risk of damage that causes leaks, causing health impacts for nearby populations and the surrounding environment. As a provider of economic activity and a source of energy in the region, damage can severely impact the local economy. Lastly, structural damage to buildings can temporarily or permanently close businesses who might need to rebuild or reinforce damaged properties. A breakdown in the transfer of goods throughout the State will cause a decline in economic activity for many export or service-based industries.

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 earthquake event could have substantial impacts to infrastructure and human life, several mitigation actions have been developed as part of the Plan update process. The three actions included in the plan for seismic activity are: conduct thorough seismic analyses of select bridge sites, based on UVM's seismic vulnerability ranking system, and prioritize projects, conduct detailed seismic analyses for critical facilities identified in the 2016 NESEC study as well as cultural facilities using HAZUS and ROVER, and partner with educational institutions to install monitoring stations across Vermont to better understand current seismic activity (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.

1. <https://www.usgs.gov/programs/earthquake-hazards/science-earthquakes> [↑](#footnote-ref-2)
2. 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. [↑](#footnote-ref-3)
3. <https://anrweb.vt.gov/PubDocs/DEC/GEO/HazDocs/Wong_2012sm.pdf> [↑](#footnote-ref-4)
4. <http://dec.vermont.gov/sites/dec/files/geo/HazDocs/Ebell_1995.pdf> [↑](#footnote-ref-5)
5. <https://earthquake.usgs.gov/data/dyfi/> [↑](#footnote-ref-6)
6. <https://dec.vermont.gov/sites/dec/files/geo/StatewidePubs/eduleaf1EQ.pdf> [↑](#footnote-ref-7)
7. <https://dec.vermont.gov/sites/dec/files/WID/Dam_Safety/Waterbury%20Dam%20Fact%20Sheet%20-201215.pdf> [↑](#footnote-ref-8)
8. <https://puc.vermont.gov/natural-gas> [↑](#footnote-ref-9)
9. <https://dec.vermont.gov/sites/dec/files/geo/StatewidePubs/eduleaf1EQ.pdf> [↑](#footnote-ref-10)
10. <https://dec.vermont.gov/sites/dec/files/WID/Dam_Safety/Waterbury%20Dam%20Fact%20Sheet%20-201215.pdf> [↑](#footnote-ref-11)
11. <https://dec.vermont.gov/sites/dec/files/WID/Dam_Safety/Waterbury%20Dam%20Fact%20Sheet%20-201215.pdf> [↑](#footnote-ref-12)