How Much Economic Damage do Large Earthquakes Cause?

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This edition of The Oklahoma Economist looks at the economic damage caused in recent decades by large earthquakes in developed countries.

The likelihood of a damaging earthquake has increased in parts of Oklahoma, according to the U.S. Geological Survey (USGS). In a May 2014 news release, the USGS said "the rate of earthquakes in Oklahoma has increased remarkably ... significantly increasing the chance for a damaging magnitude 5.5 or greater quake in central Oklahoma."[1] A subsequent release in March 2015 said "reactivated faults that have produced thousands of Oklahoma earthquakes are capable of causing larger seismic events."[2] And in January, following two moderate quakes in a one-week period in an Oklahoma City suburb, a USGS geophysicist said, "When we see two magnitude 4s in a single fault, it starts to look like something could rupture."[3]

This edition of The Oklahoma Economist looks at the economic damage caused in recent decades by large earthquakes in developed countries. It first explains the types of damage generally caused by different magnitudes and intensities of earthquakes. It then reviews the full sample of economic damages caused by past large earthquakes in the United States and other developed countries. It concludes by comparing the wide range of economic damage of these past earthquakes to the damage caused by other types of past disasters in Oklahoma and the nation.

The Richter Scale and Modified Mercalli Scale

The magnitude or size of earthquakes historically is measured through the Richter scale, introduced in 1935. This scale measures the total amount of energy released by a quake, as conveyed on a seismograph from the amount of ground movement produced by seismic waves. It is a logarithmic scale, meaning each increase in number represents a tenfold increase in shaking. For example, a magnitude 6.0 earthquake produces 10 times as much shaking as a magnitude 5.0 earthquake, and 100 times as much as a magnitude 4.0 earthquake.

The intensity of earthquakes most commonly is measured through the Mercalli Intensity Scale, developed in 1884 and modified in 1931. The Modified Mercalli Intensity Scale is divided into 12 degrees (by Roman numeral), and while these degrees generally correspond to magnitudes on the Richter scale, they can vary depending on how people and structures react to shaking. The Modified Mercalli Scale (MM) reflects the observed effects caused by earthquakes, as opposed to its overall

magnitude as conveyed by the Richter scale.

Table 1: Earthquake Magnitude, Intensity, and Effects

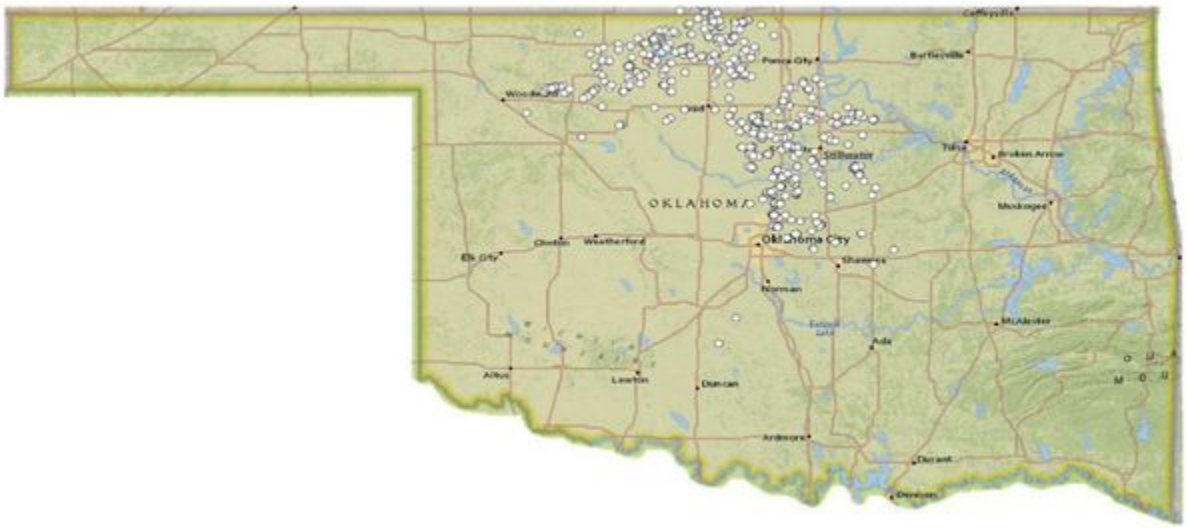
Richter Scale	Mercalli Intensity	Shaking	Description/Damage
1.0 - 3.0	I	Not felt	Not felt except by a very few under especially favorable conditions.
3.0 - 3.9	II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
	III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
4.0 - 4.9	IV	Light	Felt indoors by many, outdoors by few. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
	V	Moderate	Felt by nearly everyone. Some windows broken. Unstable objects overturned.
5.0 - 5.9	VI	Strong	Felt by all. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	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.
6.0 - 6.9	VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, monuments, walls.
	IX	Violent	Damage considerable in specially designed structures. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher	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	Total damage. Lines of sight and level are distorted. Objects thrown into the air.

Source: USGS

The typical shaking and damage from earthquakes of various magnitudes (Richter) and intensities (MM) is shown in Table 1. Earthquakes less than 2.5 on the Richter scale and II on the Modified Mercalli Scale are rarely felt. Very strong shaking and slight to moderate damage is evident starting at about 5.5 and VII on the scales, and the degree of shaking and damage increases significantly at higher magnitudes and intensities.

In 2015, the USGS reported more than 60 percent of earthquakes in the continental United States of magnitude 3.0 or greater occurred in Oklahoma. Specifically, there were 908 such earthquakes in the state last year, including 29 of magnitude 4.0 or greater. These occurred almost completely in north central Oklahoma (Map). This compares to 558 earthquakes of 3.0 or greater in all other states, including 44 quakes of magnitude 4.0 or greater and three of magnitude 5.0 or greater—one each in California, Nevada and Idaho.

Map of Oklahoma Earthquakes, Greater than Magnitude 3.0, 2015



Source: USGS

The cost of large earthquakes in developed countries, 1985-2015

The National Oceanic and Atmospheric Administration (NOAA) reports there were 195 earthquakes of magnitude 5.5 or greater in developed countries from 1985 to 2015. This includes one earthquake in Oklahoma in November 2011. That earthquake, near Prague, Okla., was a magnitude 5.7 and intensity VIII, which destroyed six houses and severely damaged 20 others. Of these 195 large quakes, the NOAA lists economic damage estimates for about a quarter of them, not including the Prague earthquake.[4] In general, damage estimates are more available for earthquakes that occur in highly populated areas. These economic damages include only direct costs, not near-term additional costs to other industries resulting from less money being spent in local areas due to the disaster. Nor do they include potential longer-term economic benefits that accrue due to increased future construction as areas are rebuilt.[5]

Table 2: 5.5 or Greater Earthquakes in Developed Countries that have Damage Estimates, 1985-2015

Date	Area	Magnitude	Mercalli Intensity	Local Population	Damage ($mil, 2015 dollars)
March 11, 2011	Japan: Honshu (main island)	9.0	n/a	103,900,000	$231,806
September 25, 2003	Japan: Hokkaido	8.3	n/a	5,627,737	$116
November 3, 2002	Alaska: Slana, Mentasta Lake, Fairbanks	7.9	9	124	$74
December 28, 1994	Japan: Honshu (main island)	7.8	9	100,751,000	$272
July 12, 1993	Japan: Hokkaido; Russia: Southeast; South Korea	7.7	8	5,692,321	$1,980
January 15, 1993	Japan: Hokkaido, Kushiro, Hachinohe, Honshu	7.6	6	106,151,000	$587
June 28, 1992	California: Landers, Yucca Valley	7.6	9	17,090	$155
April 25, 1992	California: Humboldt County: Ferndale, Petrolia	7.1	8	123,032	$127
September 3, 2010	New Zealand: Christchurch	7.0	9	376,700	$7,064
May 26, 2003	Japan: Honshu: Iwate, Miyagi, Yamagata, Akita	7.0	n/a	6,165,000	$300
January 16, 1995	Japan: SW Honshu: Kobe, Awaji-Shima, Nishinomiya	6.9	11	1,931,505	$155,529
October 18, 1989	California: Loma Prieta	6.9	9	581,335	$10,708
February 28, 2001	Washington: Olypia, Seattle, Tacoma	6.8	8	809,244	$2,677
March 24, 2001	Japan: Hiroshima, Okayama, Honshu, Kagama	6.8	9	1,855,415	$669
January 17, 1994	California: Northridge	6.7	9	1,400,000	$63,957
October 6, 2000	Japan: Honshu: W: Okayama, Tottori	6.7	9	777,081	$206
October 15, 2006	Hawaiian Islands	6.7	8	169,540	$86
October 23, 2004	Japan: Honshu: Niigata Prefecture	6.6	n/a	2,445,000	$35,128
July 16, 2007	Japan: Honshu: W Coast	6.6	n/a	2,408,000	$14,288
May 13, 1995	Greece: Grevena-Kozani, Thessaloniki, Yugoslavia	6.6	8	385,406	$700
March 2, 1987	New Zealand: North Island, Whakatani, Edgecumbe	6.6	10	257,379	$438
December 22, 2003	California: Paso Robles, Templeton, Atascadero	6.6	8	254,240	$386
June 15, 1995	Greece: Aiyion, Eratini	6.5	7	97,785	$1,026
June 17, 2000	Iceland: Vestmannaeyjar, Hella	6.5	n/a	112,960	$28
January 10, 2010	California: Off Northern Coast	6.5	n/a	135,022	$24
June 21, 2000	Iceland: Grimsnes, Selfoss, Eyrarbakki, Stokkseyri	6.5	n/a	112,960	$17
April 6, 2009	Italy: L'Aquila	6.3	n/a	298,343	$2,761
November 24, 1987	California: Superstition Hills	6.2	6	100,077	$6
July 21, 1986	California-Nevada: Chalfant Valley	6.2	6	8,795	$2
February 21, 2011	New Zealand: Christchurch, Lyttelton	6.1	n/a	376,700	$15,805
January 26, 2014	Greece: Kefalonia	6.1	n/a	35,801	$178
September 26, 1997	Italy: Central: Marche, Umbria	6.0	10	2,279,050	$6,681
September 7, 1999	Greece: Athens	6.0	9	789,166	$5,975
June 13, 2011	New Zealand: South Island: Canterbury	6.0	n/a	539,436	$3,161
August 24, 2014	California: Napa, Vallejo	6.0	n/a	200,239	$701
September 6, 2002	Italy: Sicily: Palermo	6.0	n/a	686,722	$659
September 21, 1993	Oregon: Klamath Falls	6.0	7	18,105	$12
December 17, 1987	Japan: Honshu: Chiba Perfecture, Tokyo	6.0	8	17,194,000	$10
July 8, 1986	California: Palm Springs	6.0	7	41,132	$10
May 29, 2012	Italy: Emilia Romagna: Medolla, Mirandola, Cavezzo	5.9	n/a	4,300,000	$16,309
September 13, 1986	Greece: Kalami, Lakonia, Zakinthos	5.8	10	163,992	$11
July 13, 1986	California: San Diego, Newport Beach	5.8	6	1,100,000	$2
October 31, 2002	Italy: San Guiliano Di Puglia, Campobasso	5.7	n/a	320,143	$1,049
October 1, 1987	California: Whittier	5.7	8	77,867	$747
March 25, 1993	Washington-Oregon Border	5.6	7	249,287	$47
July 25, 2003	Japan: Honshu: Miyahi, Iwate	5.5	n/a	3,770,000	$529
February 28, 1990	California: S, Claremont, Covina	5.5	7	76,380	$23
December 26, 1994	California: Eureka, Samoa, Aracata, Blue Lake	5.5	7	43,373	$3
	Simple correlation with damage	***0.43***	***0.46***	***0.42***	

Sources: NOAA, US Census, UNdata, Eurostat, Japan Statistics Bureau

Table 2 lists the 48 earthquakes in developed countries since 1985 of magnitude 5.5 or greater for which there are damage estimates. The amount of economic damage caused by these large earthquakes varies significantly, from about $2 million to more than $232 billion (in 2015 dollars). And damage varies not just for different sizes of quakes, but also for similar-sized events, which can be due to differences in local geology, population density, construction practices and epicenter location. These large differences in economic damages across even similar-sized large earthquakes, combined with their relative infrequency and differing characteristics, make it impossible to provide close estimates of the likely economic consequences of any potential future quakes.

Table 3: Average and Median Earthquake Damage, 1985-2015

Earthquakes in developed countries	Average damage ($mil, 2015 dollars)	Median damage ($mil, 2015 dollars)
All 5.5+ quakes	$12,146	$484
Magnitude > 6.5	*$23,966*	*$628*
Magnitude 5.5 to 6.5	*$2,145*	*$178*
Population > 250,000	*$20,705*	*$1,980*
Population < 250,000	*$172*	*$28*

Sources: NOAA, US Census, UNdata, Eurostat, Japan Statistics Bureau

Nevertheless, earthquake damage has been positively correlated with magnitude, intensity and population since 1985. The average damage of large earthquakes greatly exceeds median damage regardless of magnitude/intensity or population, as a few especially damaging earthquakes can skew the overall distribution (Table 3). However, looking just at medians, the median economic damage of earthquakes of magnitudes greater than 6.5 since 1985 ($628 million) is about 3.5 times higher than the median for earthquakes of magnitude 5.5 to 6.5 ($178 million). And the median damage of large earthquakes in areas with populations greater than 250,000 (nearly $2 billion) is nearly 75 times greater than for those in areas with populations below 250,000 ($28 million).

Given the relative rarity of large earthquakes in highly-populated areas of developed countries, one can gain further understanding of the possible range of damages simply by viewing and investigating the entire sample of quakes of various sizes of interest. For example, for earthquakes at or just above the 5.5 magnitude for which the USGS warned in 2014 that the chance was increasing for central Oklahoma, there are only a handful of recent comparable cases.

There were 17 earthquakes of magnitude 5.5 to 6.0 in developed countries from 1985 to 2015 for which the NOAA has estimates of economic damage. Of these, eight occurred in the far western United States, six in southern Europe, two in Japan

and one in New Zealand. The average economic damage was just more than $2.1 billion, while median damages were much less, at $529 million. But earthquake damages fell into three general groupings. In eight cases, damages were less than $50 million. These included three earthquakes away from heavily populated areas (Kalami, Greece; Eureka, Calif.; and Klamath Falls, Ore.) and five others in which the epicenter appeared to be at the edges of metropolitan areas and away from the most densely populated areas. In five other cases, damages were between $500 million and $1.1 billion. This included the most damaging U.S. case among this group, a 5.7 magnitude quake in 1987 in Whittier, Calif., a suburb between Los Angeles and Anaheim, that caused economic damage of $750 million (2015 dollars). In the remaining four cases, each of which was magnitude 5.9 or 6.0, damages exceeded $3 billion and were in heavily populated areas.

Comparison with costs of other disasters and the size of Oklahoma's economy

To get a better sense for the scale of damages from large earthquakes, they can be compared with the economic damage caused by other types of disasters. NOAA provides comparable estimates of economic damage for hurricanes, wildfires, floods, droughts, tornadoes and other disasters. In addition, further perspective can be gained by comparing damage from past earthquakes with the size of Oklahoma's state and metro economies.

Table 4: Top 10 Costliest U.S. Natural Disasters, 1985-2015

Year	Description	Estimated Cost ($bil, 2015 dollars)
2005	Hurricane Katrina	$152.5
2012	Hurricane Sandy	$67.6
1994	Northridge Earthquake	$64.0
1992	Hurricane Andrew	$45.9
1988	U.S. Drought/Heatwave	$40.2
1993	Midwest Flooding	$34.7
2008	Hurricane Ike	$33.3
2012	U.S. Drought/Heatwave	$31.2
2004	Hurricane Ivan	$25.8
2005	Hurricane Wilma	$23.2

Source: National Oceanic and Atmospheric Administration

Since 1985, six of the 10 most costly natural disasters in the United States have been hurricanes (Table 4). The largest of these, Hurricane Katrina in 2005, caused more than $150 billion in damage (2015 dollars), followed by Hurricane Sandy in 2012 at almost $68 billion. These are the only two disasters with larger economic damages than the 1994 earthquake in Northridge, Calif., a neighborhood of Los Angeles (6.7 magnitude). No other earthquake is close to making the top 10 list of most-costly U.S. disasters. The second-highest damage total from a U.S. earthquake was $10.7 billion (2015 dollars) for the 1989 Loma Prieta earthquake near San Francisco (6.9 magnitude) that happened during the 1989 baseball World Series. The third-largest was in 2001 near Seattle (6.8 magnitude) and caused damages of $2.7 billion.

Perhaps the most relevant and familiar disaster comparison for Oklahoma is tornadoes. The two tornadoes since 1985 that have caused the most economic damage in the United States occurred in 2011; one in Joplin, Mo., and the other in Tuscaloosa, Ala. Both caused between $2.5 billion and $3.0 billion in damages (2015 dollars). But the third and fourth most-damaging tornadoes in recent U.S. history both occurred in the southern part of the Oklahoma City metropolitan area, in or near Moore. The most recent one, in 2013, caused about $2.1 billion in damage, while a previous large tornado in 1999 caused damage of $1.4 billion.

The economic damage of the two Moore tornadoes is similar to the median damage of large earthquakes in highly populated areas of developed countries since 1985 ($2.0 billion). To be sure, as noted earlier, the range of damages from such earthquakes is extremely wide and can vary greatly based on magnitude, geology, population density and epicenter, not unlike the varying conditions that can affect tornado damage. So care must be taken in making such comparisons. For example, looking at just the 17 earthquakes of magnitude 5.5 to 6.0 since 1985 in the developed world, damages in 13 were less than in the Moore tornadoes, while four were greater.

Table 5: Oklahoma Gross Domestic Product, 2014

Location	2014 GDP ($millions)
Oklahoma	$183,397
OKC MSA	$72,717
Tulsa MSA	$56,027
Lawton MSA	$4,860
Non-Metro Oklahoma	$49,792

Source: U.S. Bureau of Economic Analysis

To gain more perspective about damage estimates from large earthquakes and tornados, they can be compared to the size of Oklahoma's economy. Oklahoma's gross domestic product (GDP) in 2014 was $183 billion (Table 5). This amount is slightly more than the total economic damage caused by Hurricane Katrina in 2005 and slightly less than the most damaging earthquake in modern history in 2011 on Japan's main island of Honshu. By contrast, damage from the 2013 Moore tornado—as well as from the median large earthquake in highly populated areas of developed countries from 1985-2015—would be slightly more than 1 percent of Oklahoma's GDP. Examination of the entire range of 17 magnitude 5.5 to 6.0 earthquakes that have occurred in developed countries since 1985 provides a further set of comparisons. In nearly half of those cases, damage was well less than one-tenth of 1 percent of Oklahoma GDP, while in four cases it exceeded 1.5 percent of state GDP.

Looking at the economic size of smaller parts of the state can provide further perspective. For example, GDP in the Oklahoma City metro area in 2014 was just more than $72 billion, or a little more than a third of state GDP. This is about the same as the damage caused by the 6.7 magnitude earthquake in 1994 in Northridge, Calif., the most damaging quake in recent U.S. history. For other earthquakes and tornadoes, their share of metro GDP would be slightly less than three times their share of statewide GDP.

Conclusion

Large, damaging earthquakes (magnitude 5.5 or greater) are relatively rare in developed countries, averaging fewer than seven events per year since 1985. Many occur in sparsely populated areas and thus cause relatively limited economic damage. However, a few large earthquakes have occurred in highly populated areas, with some producing significant damage and others less. The range of economic damages has varied greatly due to a variety of factors including magnitude, population density, construction practices and location of the epicenter. This article has reviewed the range of damage estimates from past large earthquakes and compared them with estimates for other types of disasters to provide perspective about their size relative to Oklahoma's economy.

Endnotes

[1] http://earthquake.usgs.gov/contactus/golden/newsrelease_05022014.php

[2] http://www.usgs.gov/newsroom/article.asp?ID=4144#.VtYGz4UrLmE

[3] http://journalrecord.com/2016/01/06/the-big-warning-geophysicist-suggests-preparing-for-stronger-quakes-energy/

[4] The NOAA's Significant Earthquake Database

[5] https://www.stlouisfed.org/Publications/Regional-Economist/April-1994/The-Economics-of-Natural-Disasters

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