The Basics of Wells – Seismic: What is the Risk?

Earthquakes can be caused by human activities. Man-made lakes, especially those at high elevations in China and India, have been directly linked to high energy earthquakes and hundreds of felt earthquakes were created by Lake Meade as it filled behind Hoover Dam. Some open pit or strip mines and waste-water water injection wells have also been linked to smaller but still troublesome earthquakes in the central US. The occurrence of seismic events in the areas of well developments has led many scientists to believe that some of the 152,000 Class II wells used specifically for oil field produced water injection and disposal are creating the sudden rise in earthquakes seen in central Oklahoma and other areas. Most of these earthquakes are minor, often below the threshold of a "felt" quake, but some are much larger and have been destructive to homes and other buildings. Studies have been theorized that perhaps 20 or more disposal wells in the central Oklahoma area are creating most of the tremors by opening deep old faults. The increase in Oklahoma seismic activity also coincides with development of the Mississippi Limestone play that produces extremely large volumes of produced water with the oil (not from fracturing fluids disposal).

To most of us, no earthquake is ever small if it is under your house, although if your foundation is on bedrock, you may feel or see evidence of very small tremors as handing lights vibrate or pendulum clocks occasionally stop for no apparent reason. There are millions of these small naturally-occurring seismic events every year and most are so small that they are not recorded. So, what is the seismic risk from natural or man-made activities and what can minimize the occurrence and impact? Creating a large seismic event requires a certain set of geologic and rock stress conditions where one part of the subterranean rock formation can move or slide past another part. "Faults" or breaks in the rock layers are very common, generally a reaction to millions of years of tectonic plate movement where the depth of the energy release is most often along deep tectonic plate margins that are subject to "stick and slide" behavior. Large quakes are also possible in areas away from the major tectonic boundaries along fault lines, such as the New Madrid fault of the central US. Smaller quakes may be triggered by injecting very large amounts of water into or near highly-stressed faults, raising pressure in the rock and lubricating rock-on-rock movement.

Seismic Event Magnitude / Intensity / Damage Comparison (Data Source USGS)	
Magnitude	Event description
-0.3 to -0.1	[Typical Range of Hydraulic Fracturing event – not felt at surface, measurable only with sensitive instruments close to the fracture growth area. Similar energy release to dropping a jug of water on the kitchen floor – this quote added by the author]
1.0 to 3.0	Not felt except by a very few under especially favorable conditions.
3.0 to 3.9	Felt by many. Vibration similar to passing of a heavy truck.
4.0 to 4.9	Generally felt – Dishes and windows broken. Unstable objects overturned.
5.0 to 5.9	Felt by all. Brick veneer damage. Damage to poorly build buildings and chimneys
6.0 to 6.9	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.
7.0 and higher	Major earthquake. Widespread damage. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.

Not every subsurface injection activity will create tremors and the great majority of disposal wells are not associated with any tremor generation.

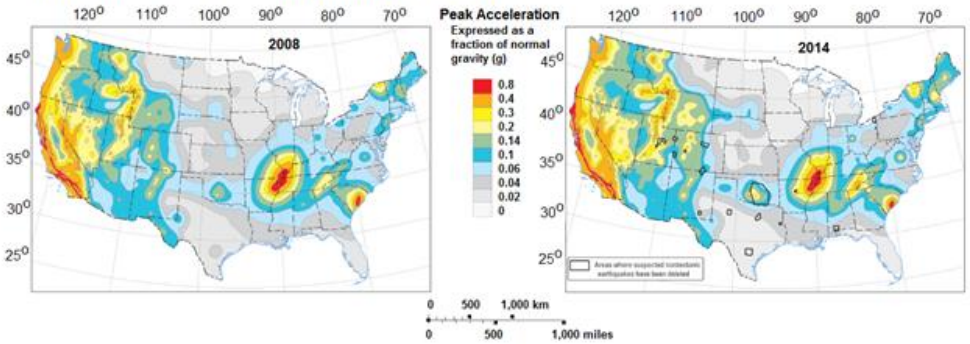
Highly damaging earthquakes, those of Magnitude 7 or higher, have occurred in a few, very specific places in the US, usually along tectonic plates or major faults. According to the USGS: "The magnitude of an earthquake is related to the length of the fault on which it occurs -- the longer the fault, the larger the earthquake. The San Andreas Fault is only 800 miles long. To generate a super earthquake with a

magnitude of over 10.0, would require the rupture of a fault that is many times the length of the San Andreas Fault. No such fault is known to exist. The largest earthquake ever recorded was a magnitude 9.5 on May 22, 1960 in Chile on a fault that is almost 1,000 miles long".

Large magnitude earthquakes usually rip open hundreds of miles of faults, often creating ground shifts and "ground waves". A 7.0 earthquake releases over three hundred billion times more energy than the average minus 2.0 magnitude seismic event from fracturing. Short duration and relatively small volume of hydraulic fracturing does not have the capacity to create high levels of seismic energy.

Determining seismic event strength (magnitude), the surface location (epicenter) and depth (hypocenter or focus) are becoming better with time because of the increase of monitoring stations from the few hundred stations worldwide in the 1930's to the tens of thousands of monitoring stations today. Closer station positioning results in sensing and locating more of the small quakes that were previously undetected before and the earthquake risk maps for the US have shown small changes in some areas.

Maps showing peak ground acceleration for 2% probability of exceedance in 50 years and VS30 site condition of 760 m/sec



Reproduced from USGS Earthquake Hazards Program. 2014. Lower 48 Maps and Data. http://earthquake.usgs.gov/hazards/products/conterminous/. (accessed 29 July 2015).

USGS earthquake risk maps of 2008 and 2014, using increased numbers of monitoring stations and portable monitoring stations, have helped redefine most areas of risk. Note that risk has increased in a few areas such as central Oklahoma where induced seismic from injection wells is suspected and fault mapping has identified higher risks. A few tremors also occurred in the Fort Worth, Texas, area, where a few injection wells were reportedly pushed beyond their rated limits of total volumes. The Texas Railroad Commission has set out new rules the react to any tremors that may be associated with injection and new regulations are being advanced that control the design, location and depth of the wells, plus the volume and rate at which fluids can be injected.

The risk of produced water disposal creating even a felt earthquake is very low in most areas, but if the wells are loaded with water volumes beyond what they can safely accept, then tremors are likely. Water injection limits are set by state regulators that are familiar with local conditions and rock formation behaviors. Site selection and setting of volume and rate limits are critical to safe injection behavior.

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