Overview of Induced Seismicity

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Outline

• Mechanics of induced earthquakes

• Increased earthquake activity in the U.S. midcontinent
Mechanics of Induced Earthquakes

Changes in solid stress due to fluid extraction or injection (poro-thermoelastic effects, changes in gravitational loading)

Direct fluid pressure effects of injection (fluid pressure diffusion)

Volume and/or mass change

Permeable reservoir/aquifer

Increase in pore pressure along fault (requires high-permeability pathway)

Change in loading conditions on fault (no direct hydrologic connection required)
Mechanics of Induced Earthquakes: Solid Stress Effect

THE EVOLUTION OF SEISMIC BARRIERS AND ASPERITIES CAUSED BY THE DEPRESSURING OF FAULT PLANES IN OIL AND GAS FIELDS OF SOUTH TEXAS

By Wayne D. Pennington*, Scott D. Davis, Steven M. Carlson†, James DuPree‡, and Thomas E. Ewing§

The earthquakes in the Fashing and Pleasanton areas of South Texas are due to the withdrawal of fluids from the Fashing gas field and the Imogene oil field.

The 9 April 1993 Earthquake in South-Central Texas: Was It Induced by Fluid Withdrawal?

by Scott D. Davis, Paul A. Nyffenegger, and Cliff Frohlich

The available evidence strongly suggests that the Fashing, Pleasanton, and Falls City earthquakes were all triggered by hydrocarbon production (Pennington et al., 1986; Olson and Frohlich, 1992).

Fig. 1. Map of area in South Texas containing induced earthquakes. Shaded regions are more prominent oil and gas fields. Isocenters for largest events are indicated in Modified Mercalli Intensity scale. Locations of cross-sections in Figure 2 are indicated.
Mechanics of Induced Earthquakes: Pore Pressure Effect

- Ancient faults can be reactivated by decreasing the effective normal stress

$$\tau_{\downarrow crit} = \mu (\sigma n - P)$$

- Faults occur on a wide variety of scales and are found in virtually every geologic setting

- The Earth’s crust is in a near critical failure state everywhere

W.-Y. Kim, Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio. J. Geophys. Res. 10.1002/jgrb.50247 (2013)


Mechanics of Induced Earthquakes
These are not new ideas

Subsurface Disposal in Geologic Basins – A study of Reservoir Strata
AAPG Monograph 10 (1968)

Underground Waste Management and Environmental Implications
AAPG Monograph 18 (1976)

“the tremors ... being the results of the release of stress when the pressures produced by injection of fluid overcome the friction on opposing rock surfaces.”

“The Denver earthquakes – and similar, less intensively studied cases in oilfields in western Colorado, Texas and Utah – have served a very good purpose in alerting us to this kind of long-term danger.”
“The disposal of waste fluids by injection into a deep well has triggered earthquakes near Denver, Colorado.”


Key Findings:

• Release of long-stored tectonic stress on ancient faults
• Earthquakes occurred more than 10 km from injection point
• Largest earthquake (Mw 4.8) occurred over one year after injection stopped
• Earthquakes continued into the 1980s
USGS experiment turned on and off earthquakes in a Colorado oil field by varying injection pressure.

State of stress and pore pressure were measured, as was the frictional strength of the rocks.

\[ \tau_{\text{crit}} = \mu (\sigma_n - P) \]

“The cessation of seismic activity within 1 day of the initiation of backflow in the experimental wells in May 1973 established the correlation between fluid pressure and earthquakes beyond a reasonable doubt.”

Hazard model for the central and eastern U. S. primarily based on past seismicity

What rate of earthquakes should be expected in the future?
Higher rate of earthquakes implies higher hazard.

But how much higher?

And where has the hazard increased?

Hazard model for the central and eastern U. S. primarily based on past seismicity.
The earthquake rate in north-central Oklahoma (and southern Kansas) increase follows the drilling front by about one year.
1980 - 1989

Annual Frequency of Occurrence (OGS Catalog)

Oklahoma Geological Survey Catalog 1980 - 1989
2014 through May

\[ P(M \geq 5\frac{1}{2}) = 0.23 \text{ to } 0.53 \]
in the next 12 months

Compared with the 1970-2008 expectation of
\[ P(M \geq 5\frac{1}{2}) = 0.003 \]
Higher rate of earthquakes implies higher hazard.

But how much higher?

And where has the hazard increased?

Earthquakes for October, 2014
Magnitude $\geq 2.5$
Thank You