Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany

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Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany

- Felt or damaging induced earthquakes are of public concern and of legal significance.

- Develop models describing relation between intensity, magnitude and distance (“intensity prediction equations, IPE”) for induced earthquakes in Germany
Data

- Earthquake database for Germany GERSEIS
- 5350 induced earthquakes
- 182 induced earthquakes with intensity and magnitude ($ML$) (1940-2015)
- 47 induced earthquakes with mean isoseismal radii and $ML$

- 17 macroseismic maps of seismic events in mining areas in Germany
Data

- Mining induced seismic events with moderate to severe building damage (intensity 7 and 8) have so far only occurred in potash and salt mining.

- Slight building damage (intensity 6) has also been caused by seismic events in coal mining.

- Over the past 20 years, the frequency of felt earthquakes has increased in regions with natural gas production and in recent years also in regions of deep geothermal energy production.
Völkershausen 1989, rockburst in potash mining
Leydecker, Grünthal, Ahorner (1998)

N = 182

Number of events vs. magnitude (ML) and focal depth (km)

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IPE

\[ I = a + b \, M + c \, \log R + d \, R \]

- \( I \): intensity
- \( M \): magnitude
- \( R \): hypocentral distance

**Constants**
- \( a \): scaling
- \( b \): energy release
- \( c \): geometrical spreading
- \( d \): anelastic attenuation

**Mean Isoseismal Radius**

\[ R = (R_{\text{epi}}^2 + h^2)^{-1/2} ; h = \text{focal depth} \]

47 induced earthquakes with \( R_{\text{epi}}(I = 3, 5, 6, 7, 8), h, \text{and } ML \)
Musson (2005): \[ I = 3.31 + 1.28ML - 1.22 \ln R \]

\( R \) in (km)
Musson (2005): \[ I = 3.31 + 1.28ML - 1.22 \ln R \]

Tosi et al. (2015): \[ I = 2.31 + 1.03ML - 2.15 \log R \]

\( R \) in (km)
2016: Revision of Federal Mining Act “Bundesberggesetz”

- Damages within the “affected area” ("Einwirkungsbereich") of an induced seismic event shall be presumed to be caused by the mining operation, and compensation shall be paid by the mining company.

- The “affected area” shall be defined by the mining authority.

- Thresholds to define the “affected area”:
  - peak ground velocity PGV: 5 mm/s
  - macroseismic intensity: 5 EMS
For damaging induced seismic events in the mining regions of Germany:

- Few PGV measurements
- Extensive macroseismic observations
Goal

- Find a conservative and simple relationship to estimate the „affected area“ from $ML$, epicentral coordinates and focal depth

Data and Method

- Analyze published macroseismic maps of seismic events in mining areas in Germany (N=17)
- Observed maximum hypocentral distances to intensity 5
Example 1
11.09.1996 Teutschenthal, potash mining, $ML = 4.9$

Tittel et al. (2001)
Example 2
13.07.1981 Ibbenbüren, coal mining, $ML = 4.1$

Harjes et al. (1983)
Example 3
11.07.2002 Weyhe, gas extraction, $ML = 2.3$

Leydecker (2003)
Example 4

08.12.2006 Basel, geothermal stimulation, $ML = 3.6$

Ripperger et al. (2009)
maximum hypocentral distance to intensity 5 (km)
maximum hypocentral distance to intensity 5 (km) vs ML

- gas
- geothermal
- potash
- coal
maximum hypocentral distance to intensity 5 (km)

ML

gas
geothermal
potash
coal
Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany – Conclusions

1. Focal depths show a large influence on the relationship between $M$ and $I$. Intensity 5 has been observed for shallow (~1 km depth) events with magnitudes as small as $ML=1.8$.

2. Simple models of the form $I = a + b M + c \log R$, with $R =$ hypocentral distance, can be fitted to the observations. Models for tectonic earthquakes do not fit for induced earthquakes; for induced seismic events $I$ is smaller for a given $M$ and $R$.

3. Major differences were found between different mining areas: In gas production areas intensity 5 effects were always observed at greater hypocentral distances for a given magnitude, compared to coal and potash mining areas.
Relationship between magnitude, macroseismic intensity and distance for induced earthquakes in Germany – Next steps…

1. Extend database

2. Analyze differences between different mining areas. Different attenuation properties?

3. International comparison

4. Analyze PGV

5. Since macroseismic data (especially intensity data points) in Germany are available almost exclusively in analog form and are often difficult to access, it is necessary to establish a database for induced earthquakes including macroseismic data.