Shale Gas Extraction and CCS May Induce Serious Seismicity

Y. Fujii[a]*, K. Takahashi[a], D. Fukuda[a] and J. Kodama[a]

[a] *Hokkaido University, Sapporo, Japan*
* fujii6299@frontier.hokudai.ac.jp (*corresponding author's E-mail)*

Abstract

An equation that represents the relationship between the volume of the injected water V and the maximum magnitude $M_{\max}$ of induced earthquakes for various cases, including EGS (Enhanced Geothermal System), is expressed as

$$M_{\max} = 0.75 \log V - 0.48 \tag{1}$$

Another equation that represents the relationship between the magnitude and the JMA (Japan Meteorological Agency) maximum seismic intensity scale $SIS_{\max}$ of 40 randomly-selected, inland earthquakes in Japan is expressed as:

$$SIS_{\max} = 1.36M - 1.12 \log d - 1.11 \tag{2}$$

where d is the focal depth (m). The equation that follows was derived from the preceding equations.

$$SIS_{\max} = 1.02 \log V - 1.12 \log d - 1.76 \tag{3}$$

The volume of water injection by shale gas extraction in US was estimated and substituted into the equations, assuming that Eq. (2) could be used also for US earthquakes. The maximum magnitude and seismic intensity scale was predicted to be 6.0 and 3.5 (slight damage to residences), respectively, for the case where extraction had continued for 30 years. This estimate does not conflict with the fact that an M 5.6 event occurred five years after shale gas extraction began in the US.

The same procedure was adopted for CCS (Carbon dioxide Capture and Storage) assuming that supercritical CO_2 injection had the same effect in inducing seismicity. The injection volume is just 0.001% of the annual CO_2 emission in Japan assuming that the allowable seismic intensity scale is 1. The injection of this small amount of CO_2 is meaningless. We may have an M 7.1 whose SIS is 5.3 (heavy, significant damage to residences) if we inject 17% (this is IPCC's expectation) of the CO_2 in Japan for 30 years into a CCS site. An M 7.1 is apparently not allowed. We need 510,000 CCS sites in Japan in order to inject 17% CO_2 safely. It is impossible to construct so many CCS sites.

In conclusion, either shale gas extraction or CCS should be carried out very carefully or we may have severe seismicity.

Keywords: Shale Gas Extraction, CCS, Induced Seismicity

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Yoshiaki FUJII, Kei TAKAHASHI,
Daisuke FUKUDA and Jun-ichi KODAMA

Rock Mechanics Laboratory, Hokkaido University, JAPAN

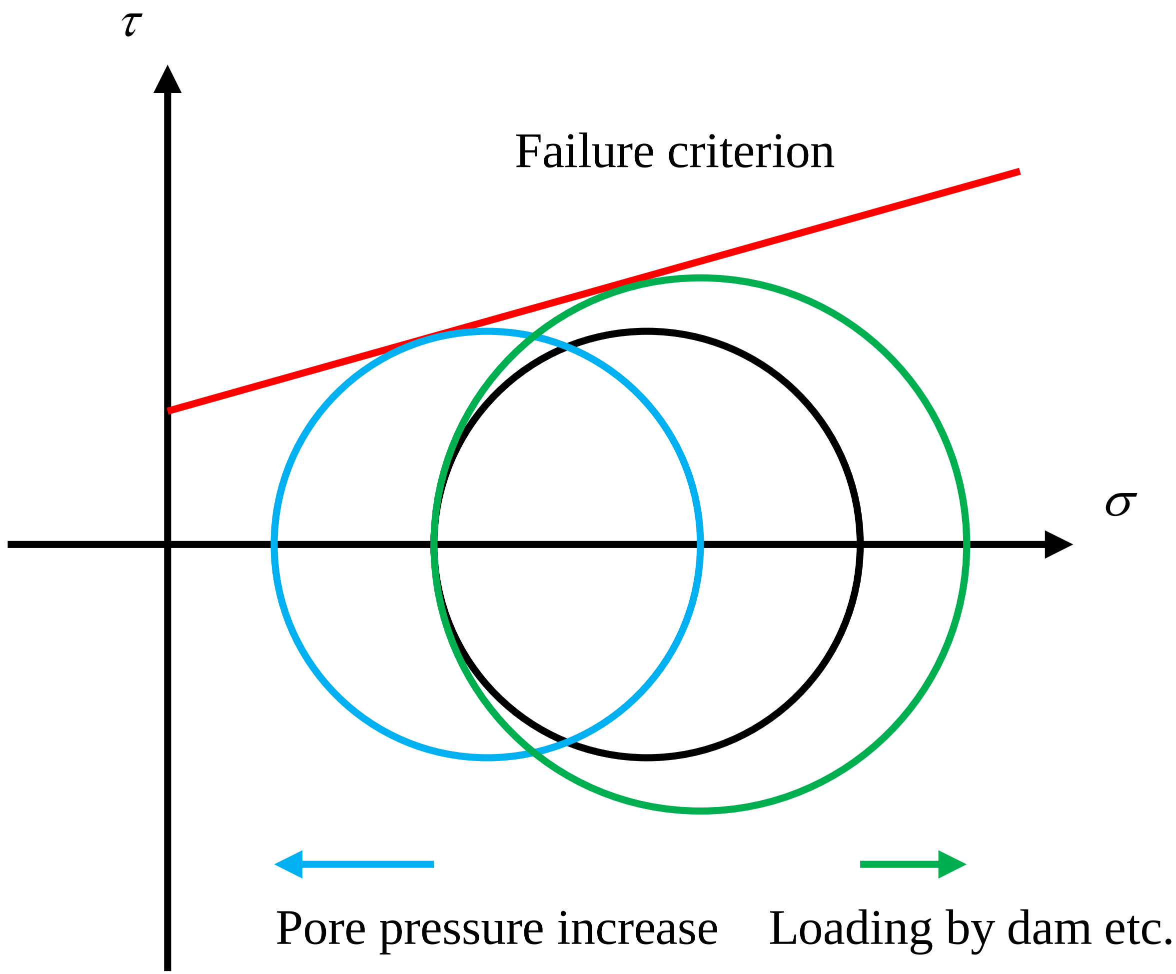
20 min. incl discussion.

Background and objectives

- Such new underground utilizations as shale gas extraction, CCS, etc. are being practiced.
- IIS (Injection Induced Seismicity) by EGS (Enhanced Geothermal System) as well as induced seismicity by dam construction, deep coal mining, etc. are well known.

- IIS by shale gas extraction and CCS is estimated.

Mechanisms of induced seismicity



Case studies of IIS

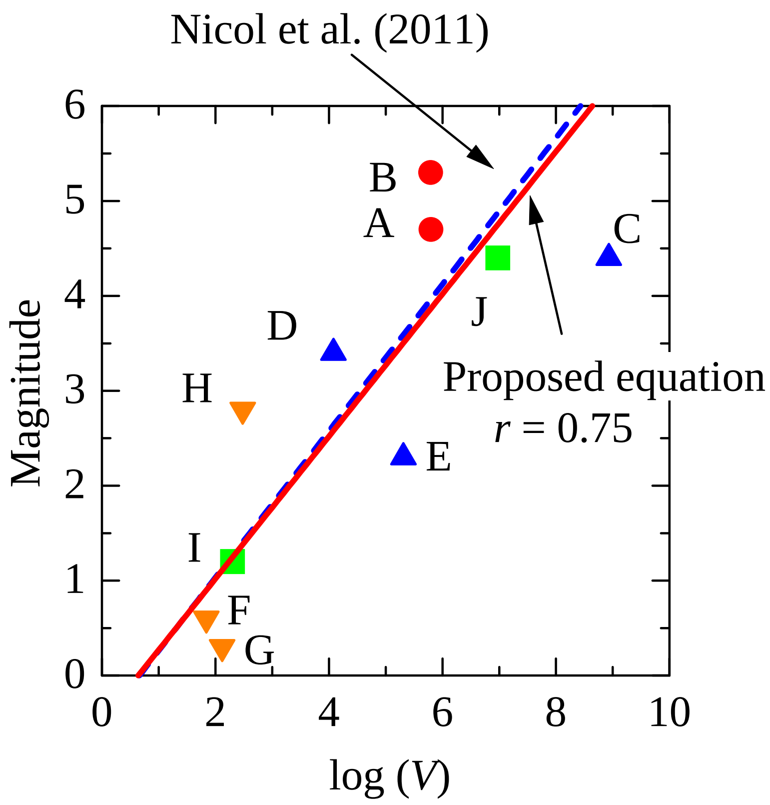
- Injection of contaminated water in Denver: M5.3
- Water injection in EGS in Geysers, California: M4.7
- Waste water from hydrofrac for enhanced recovery of natural gas in Arkansas: M4.7
- Injection of brine from rocksalt dome in Paradox Valley, Colorado: M4.4

Estimation of severity of seismicity

Used data

	Site	Fluid	Injection depth (m)	Injected volume (m^3)	Max. magnitude	References
A	Well 1& Well 5, North Central Arkansas , US (2010)	Waste water disposal, a byproduct of hydrofracking	1800	630000	4.7	Horton (2012)
B	Denver, US (1962-1967)	Chemically contaminated waste water	3700	620000	5.3	Healy et al. (1968)
C	The Geysers, US (1972-2006)	Water for EGS	6500-8500	850000000	4.4	Convertito et al. (2012), Cladouhos et al. (2010)
D	Basel 1, Switzerland (2006)	Water for EGS	5000	12000	3.4	Ladner & Häring (2009)
E	GPK3, Soultz, France (1987-2007)	Water for EGS	5000	205000	2.3	Nocolas et al. (2011)
F	Nojima fault, Japan (1997)	Water for experiment	540	69	0.6	Nishigami et al. (2002)
G	Nojima fault, Japan (2000)	Water for experiment	540	131	0.3	Nishigami et al. (2002)
H	Matsushiro, Japan (1970)	Water for experiment	1800	302	2.8	Nishigami et al. (2002)
I	KTB, Germany (1994)	Potassium salt solution for experiments	9030	200	1.2	Nishigami et al. (2002)
J	Paradox Valley, US (2013)	Brine disposal	4300-4800	9500000	4.4	Block et al. (2014)

Magnitude from injected water volume



$$M_{\max} = 0.75 \log V - 0.48$$

$M_{\max}$ maximum magnitude

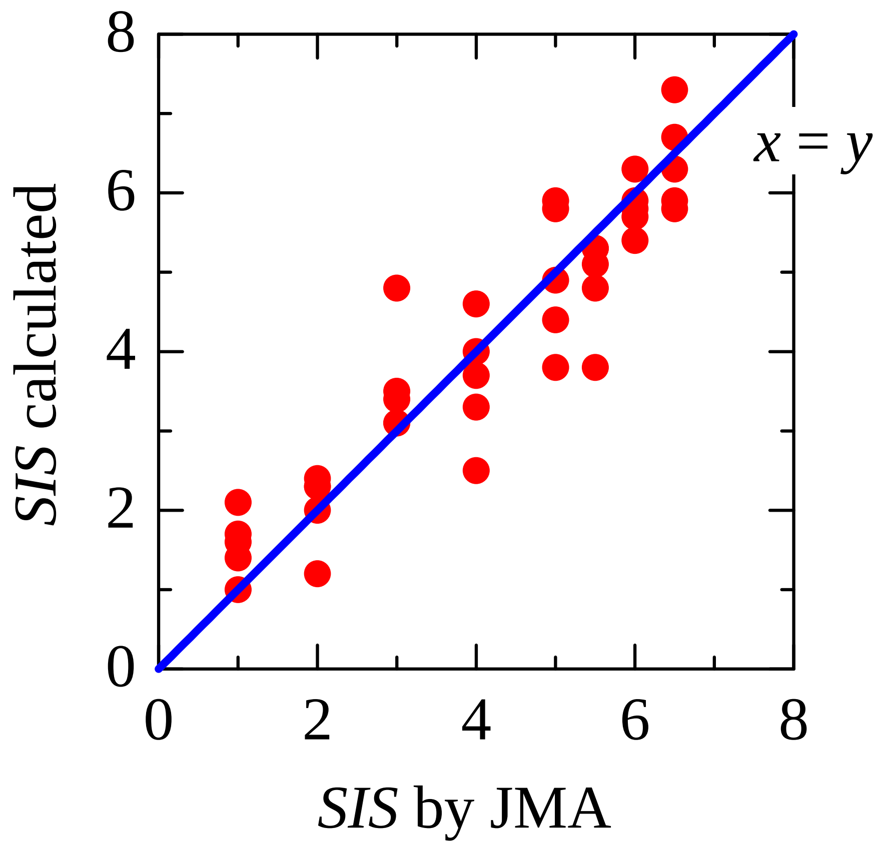
V injected water volume (m^3)

Maximum seismic intensity scale from magnitude and focal depth

- Based on randomly chosen 40 inland earthquakes in Japan.

$$SIS_{\max} = 1.36M - 1.12\log d - 1.11$$

$SIS_{\max}$	maximum seismic intensity scale (JMA)
M	magnitude
d	depth (m)



JMA (Japan Meteorological Agency) seismic intensity scale

Meter reading	Effect on people	Damage on less earthquake-resistant houses	Peak ground acceleration (m/s^2)
0	Not felt	No damage.	< 0.008
1	Felt by some people indoors.	No damage.	0.008 - 0.025
2	Felt by many to most people indoors.	No damage.	0.025 - 0.08
3	Felt by most to all people indoors.	Slight damage.	0.08 - 0.25
4	Many people are frightened.	Slight damage.	0.25 -0.80
5-lower	Most people try to escape.	Suffer damage to walls and pillars.	0.80 - 1.40
5-upper	Many people find it difficult to move.	Heavy/significant damage.	1.40 - 2.50
6-lower	Difficult to keep standing.	Collapse.	2.50 - 3.15
6-upper	Impossible to keep standing.	Collapse.	3.15 - 4.00
7	Thrown by the shaking.	Severe damage no matter how earthquake-resistant.	> 4.00

Maximum seismic intensity scale from injected water volume and focal depth

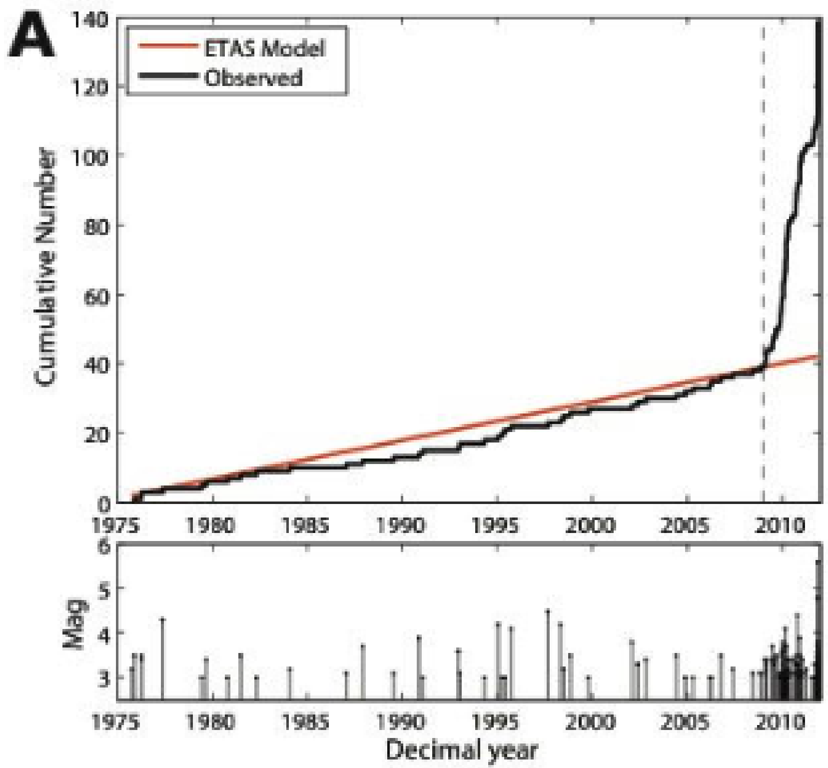
$$SIS_{\max} = 1.02 \log V - 1.12 \log d - 1.76$$

$SIS_{\max}$	maximum seismic intensity scale (JMA)
V	injected water volume (m^3)
d	focal depth (m)

Shale gas extraction

Assuming that the relationship between *SIS*, *d* and *M* can be used to earthquakes in US.

- Number of earthquakes in the Central U.S. increased suddenly in 2009 with shale gas extraction.
- It was statistically proven that the increase was not a natural process.
  - Lleons & Michael (2012)
- There were shale gas wells within 5 km of hypocenters for Ohio cases.
  - Fukuda (2013)



Water volume

- Oil & natural gas
  - Associated water volume: 0.63% of oil equivalent volume
  - Treated and injected.
- Shale gas
  - Hydrofrac: 33% of oil equivalent volume of shale gas.
  - Flow back water (15 - 25% in 30 days) is also treated and injected.
- 50 times water is injected in shale gas extraction to get the same energy.
  - Severer induced seismicity than conventional oil & gas extraction is anticipated.

Results

Site	Water volume (Mm^3/y)	1 year extraction		30 year extraction	
		M_{max}	SIS_{max}	M_{max}	SIS_{max}
Barnett TX	7.1	4.7	1.7	5.8	3.2
Fayetteville AR	5.1	4.6	1.6	5.7	3.1
Haynesville LA	2.7	4.3	1.3	5.5	2.8
Marcellus NY/PA/WV	< 13.5	4.9	2.0	6.0	3.5

*Depth of injection and hypocenter were assumed to be 1300 m.

- M6.0 and SIS3.5 would be OK in Japan.
- But how it will be in US?
  - M6.0 Napa Valley earthquake (d = 11.3 km) on Aug. 24, 2014 destroyed the wineries.

From CNN Web Site

CCS

Assuming that effects of supercritical CO_2 to induce seismicity is the same as those of water.

Conditions

- d > 800 m from the supercritical conditions.
  - P > 7.4 MPa and T > 304 K
- ρ = 469 (kg/m^3) at supercritical condition.
- CO_2 emission in Japan
  - 2.56 Gm^3/y (supercritical)

Allowable injection volume for a site

- Assuming that
  - allowable *SIS* is 1 (felt by some people indoors) and
  - a site operates for 30 years.
- 26,000 m^3/y can be injected with $M_{max} = 3.9$
  - Just 0.001% of annual CO_2 emission.
- Too little!
- No effects!
- Meaningless!

IPCC wants to inject 17% of CO_2 emission

- If we inject 17% CO_2 from Japan into a site for 30 years,
  - We may have a M7.1 directly underneath.
  - SIS_{max} = 5.3 (heavy, significant damage)

- Out of question!
- Apparently unallowable!

How many sites do we need to keep earthquakes allowable?

- We need 510,000 CCS sites!
- Impossible!

CCS projects in Japan

- Nagaoka
  - 20,000 m^3 CO_2 into sandstone at 1,100 m deep.
  - M_{max}: 2.7, SIS_{max}: -2
  - It's natural that there were no felt earthquakes.
- Tomakomai
  - More than 640,000 m^3 CO_2 into sandstone and conglomerate.
  - M_{max}: 3.9, SIS_{max}: 0.4
  - It's natural that there will be no felt earthquakes.
  - Having no felt earthquake does not mean that CCS is safe.

What do others say?

- Zoback & Gorelick (2012) and Zoback (2013)
  - Shale gas is OK whereas CCS could be dangerous.
- Cappa & Rutqvist (2012 and 2011) and Nicol et al. (2011)
  - CCS could be dangerous.

Concluding remarks

- Shale gas extraction may induce severe seismicity.
- CCS may become either meaningless or dangerous.
- Enough attention should be paid to induced seismicity when extracting shale gas or carrying out CCS.

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