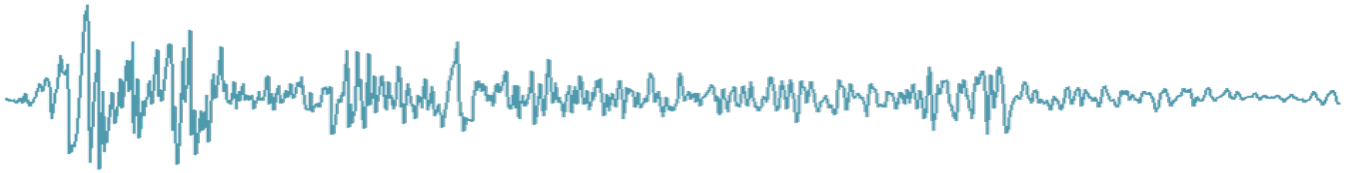
University of BRISTOL

22-25 June - Hydra, Greece

The 42nd Risk, Hazard and Uncertainty Workshop



Human-induced earthquakes:

an opportunity to seek stakeholders' attention on energy-based and cumulative damage in PBEE

Flavia De Luca (flavia.deluca@bristol.ac.uk)

Acknowledgements…

Max Werner
Lecturer @ Earth Science,UoB

James Verdon
Research fellow @ Earth Science,UoB

Cabot Institute Innovation Fund 2015-2016

"Natural earthquakes as proxies for man-made seismic hazard and risk: understanding induced earthquakes, their ground motions and building vulnerability in the UK"

Stefanos Kythreotis
4thyear UG student @Civil Eng, UoB

bristol.ac.uk
flavia.deluca@bristol.ac.uk

The research questions…

Some evidence suggests that induced earthquakes cause ground motions that are different from those of natural ones: anthropogenic tremors are shallower and appear to generate smaller stress drops.

Do we expect any difference in structural response (and consequently damage) from human-induced earthquakes with respect to low magnitude tectonic ones?

Do we need bespoke EDP measures (e.g., energy-based)?

Are we finally, seriously implementing in codes energy-based capacities thanks to stakeholder ‘s attention on this topic?

Pilot-study to assess the first question (mainly methodologically)

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flavia.deluca@bristol.ac.uk

Human-induced earthquakes…

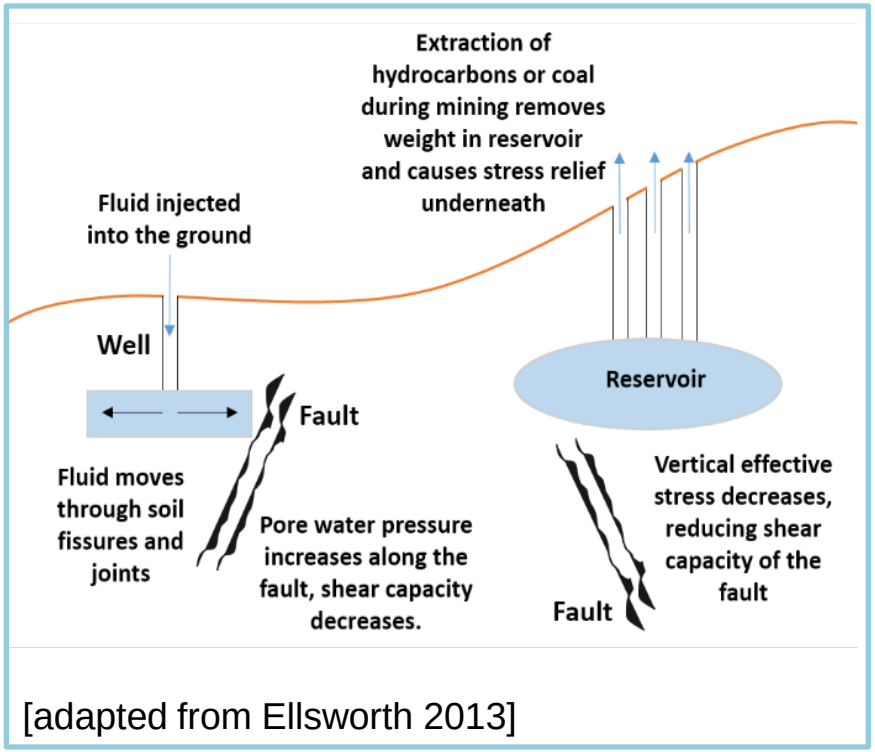
Human-induced earthquakes are produced by a variety of different activities (e.g., fracking, wastewater disposal, geothermal energy production, carbon capture and storage and coal mining).

The largest injection-induced event in **Oklahoma** in 2011 M_L 5.6 triggered by wastewater disposal.

In UK, **Blackpool** fracking-induced M_L 2.3 event in 2011.

2012 M_L 3.6 event in the **Groningen** field of the Netherlands (huge number of damage claiming)

M_L 3.4 earthquake at the **Basel** geothermal site in Switzerland in 2006.



[adapted from Ellsworth 2013]

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flavia.deluca@bristol.ac.uk

[1] Induced events here are those caused by fluid injection.

Collecting data…

Data were downloaded from IRIS (http://www.iris.edu). The challenge is to retrive the exact starting time of the events, in particular for human-induced earthquakes (i.e., both caused by fluid injection, and mining).

- Healy, J., Rubey, W., Griggs, D., and Raleigh, C. (1968). The Denver Earthquakes: Disposal of waste fluids by injection into a deep well triggered earthquakes near Denver, Colorado. Science 161(3848)
- Kim, W.-Y. (2013). Induced seismicity associated with fluid injection into a deep well. Journal of Geophysical Research: Solid Earth 118(7): 3506–3518.
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- Rubinstein, J., Ellsworth, W., McGarr, A., and Benz, H. (2014). The 2001–Present Induced Earthquake Sequence in the Raton Basin of Northern New Mexico and Southern Colorado. Bulletin of the Seismological Society of America 104(5): 2162–2181.
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- Wilson, M., Davies, R., Foulger, G., Julian, B., Styles, P., Gluyas, J., and Almond, S. (2015). Anthropogenic earthquakes in the UK: A national baseline prior to shale exploitation. Marine and Petroleum Geology 68(A): 1-17.
- Petersen, M.D., Mueller, C.S., Moschetti, M.P., Hoover, S.M., Rubinstein, J.L., Llenos, A.L., Michael, A.J., Ellsworth, W.L., McGarr, A.F., Holland, A.A., and Anderson, J.G. (2015). Incorporating induced seismicity in the 2014 United States National Seismic Hazard Model - Results of 2014 workshop and sensitivity studies: U.S. Geological Survey Open-File Report 2015–1070.
- Natural Resources Canada (2016). Earthquakes Canada, GSC, Earthquake Search (On-line Bulletin), [online]. See http://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-eng.php (accessed 06/02/2016)

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Collecting data…

$$PGA \geq 0.1^{*}\ cm/s^{2} \quad \& \quad R_{epi} \leq 300\ km$$

*lowest value of PGA equivalent to MMI 2 (Worden et al. 2012)

	Number of Waveforms								
Region\Type	**Natural**			**Mining**			**Injection-Induced**		
	Events	**Components**		**Events**	**Components**		**Events**	**Components**	
		Horizontal	**Vertical**		**Horizontal**	**Vertical**		**Horizontal**	**Vertical**
UK	20	44	23	1	2	1	-	-	-
US	-	-	-	-	-	-	6	26	12
Canada	-	-	-	16	44	23	-	-	-
Total	20	**44**	23	17	**46**	24	6	**26**	12

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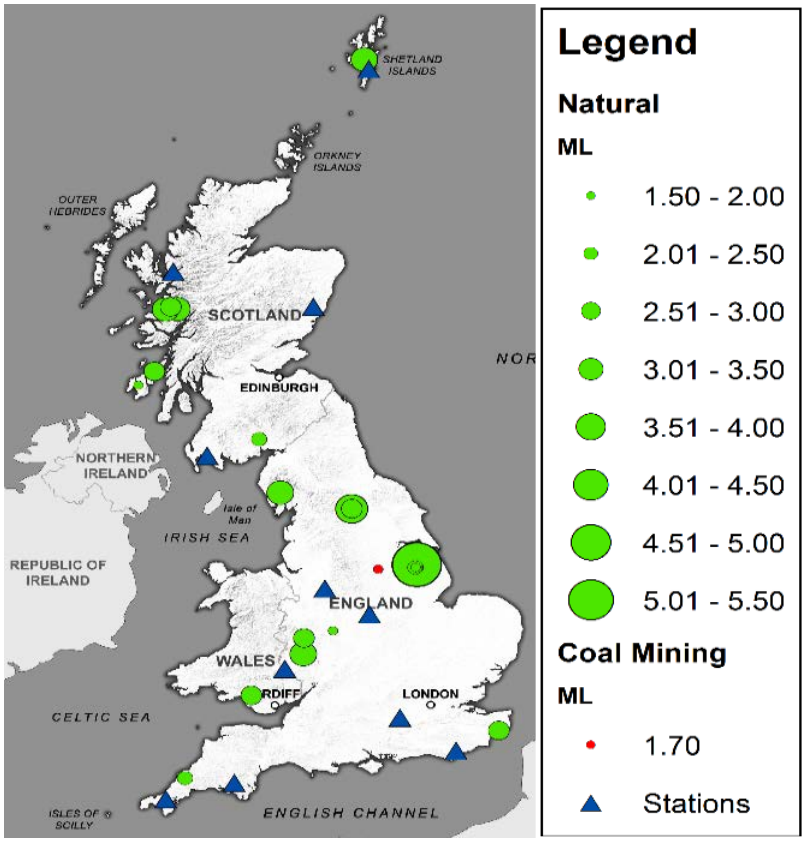
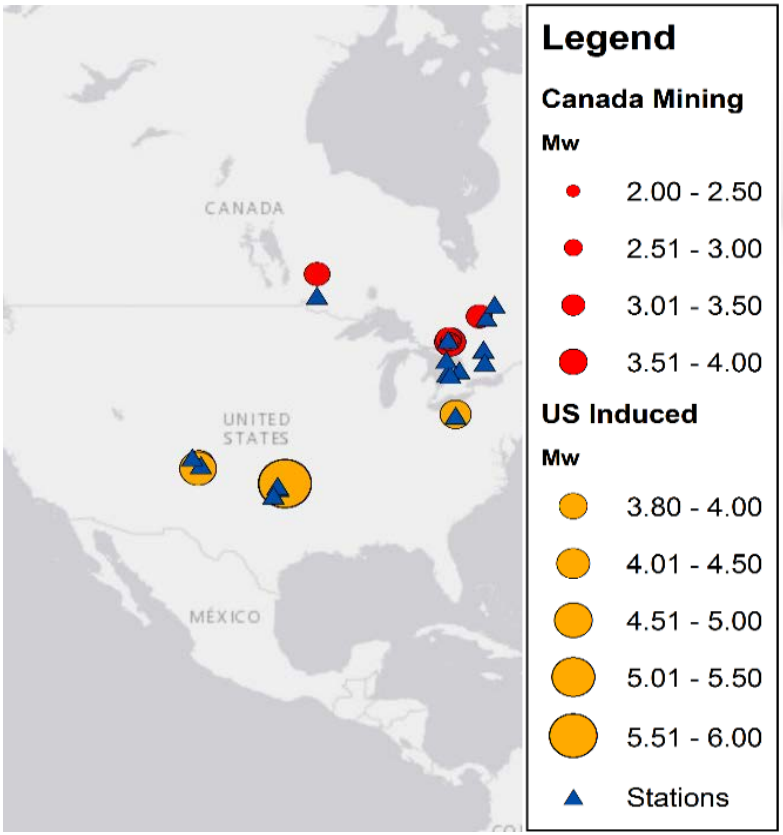
Collecting data…





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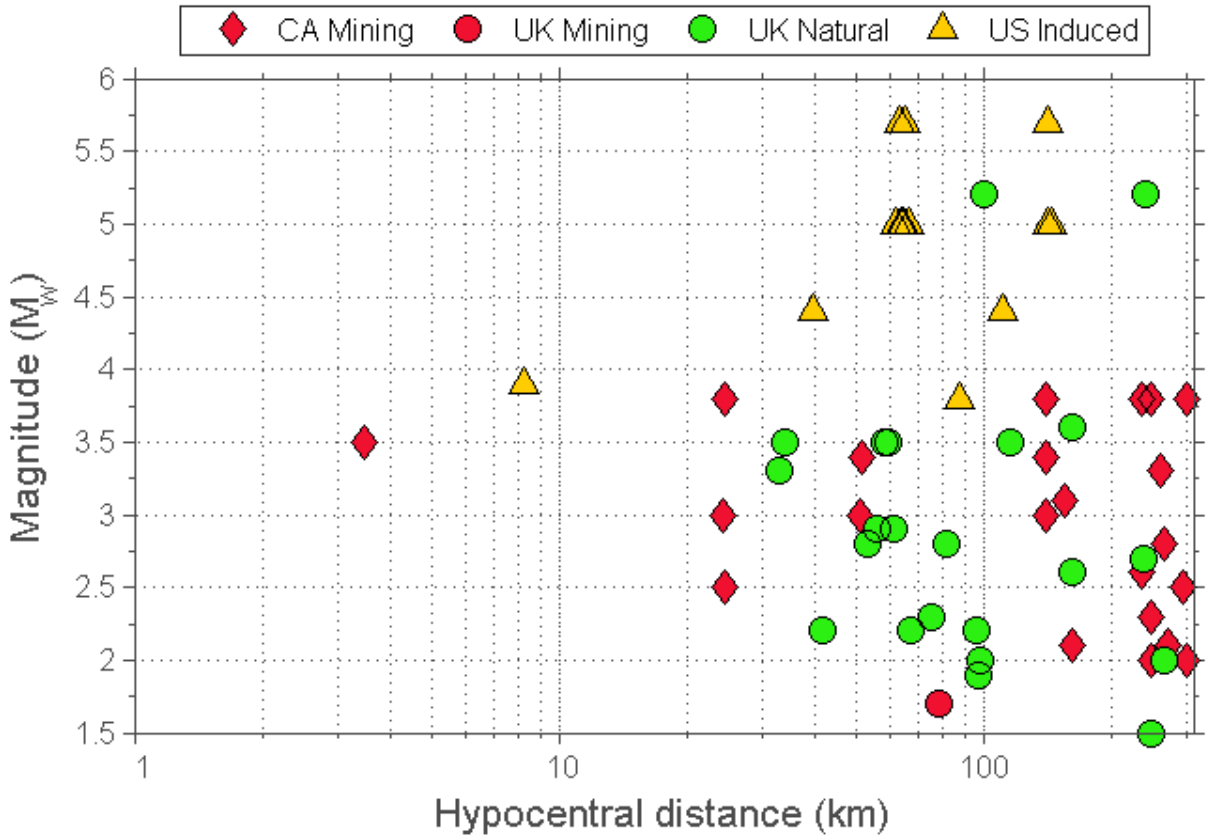

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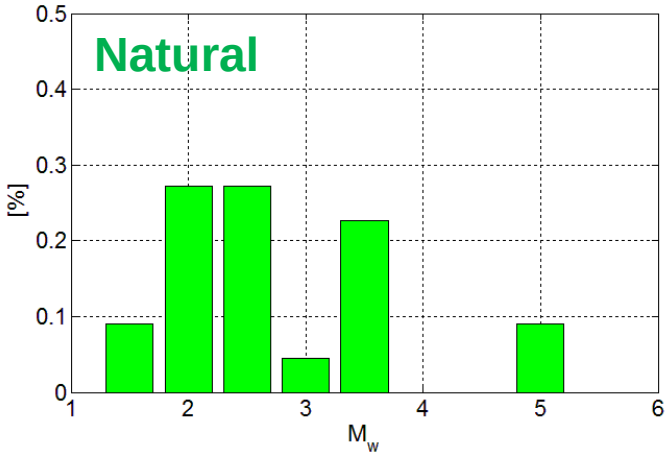
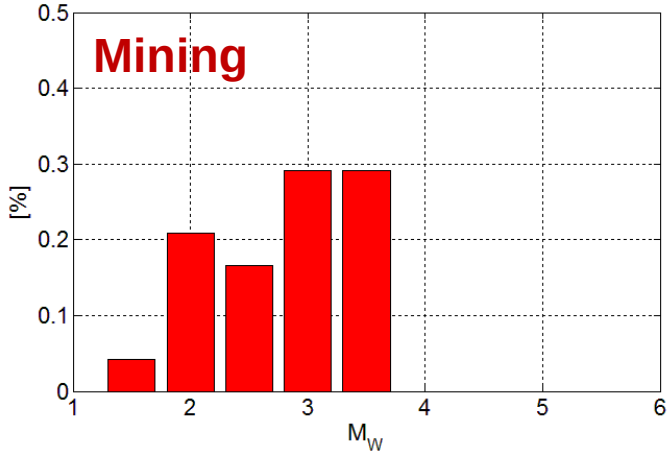
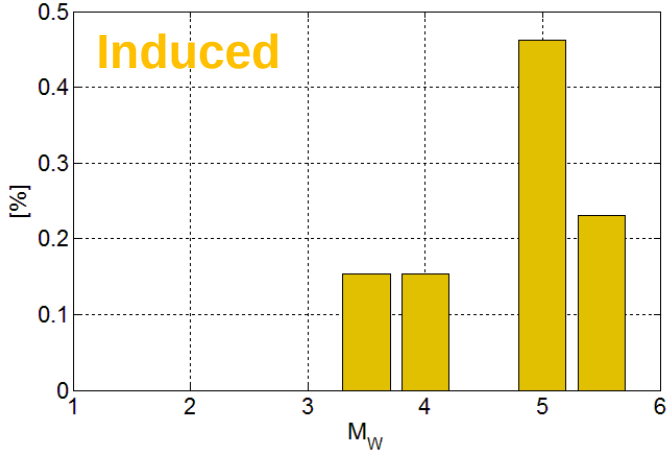
Collecting data…



Natural and mining have sufficient overlapping, induced dataset has higher median magnitudes.





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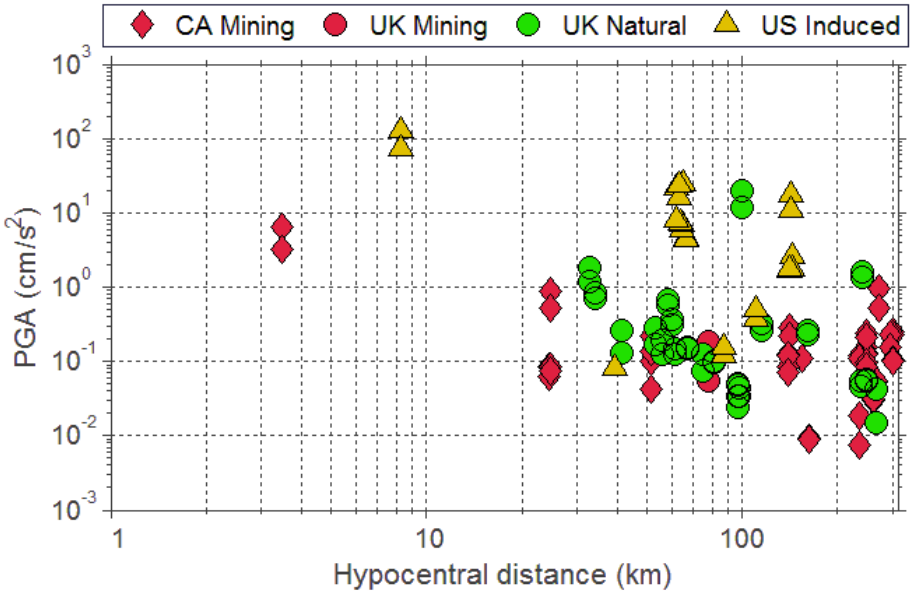
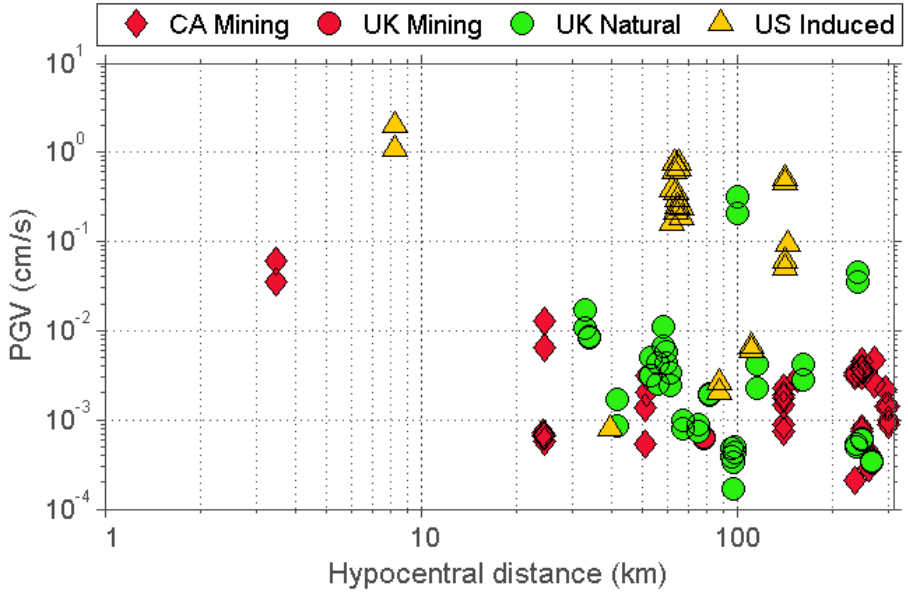
Ground motion characteristics…





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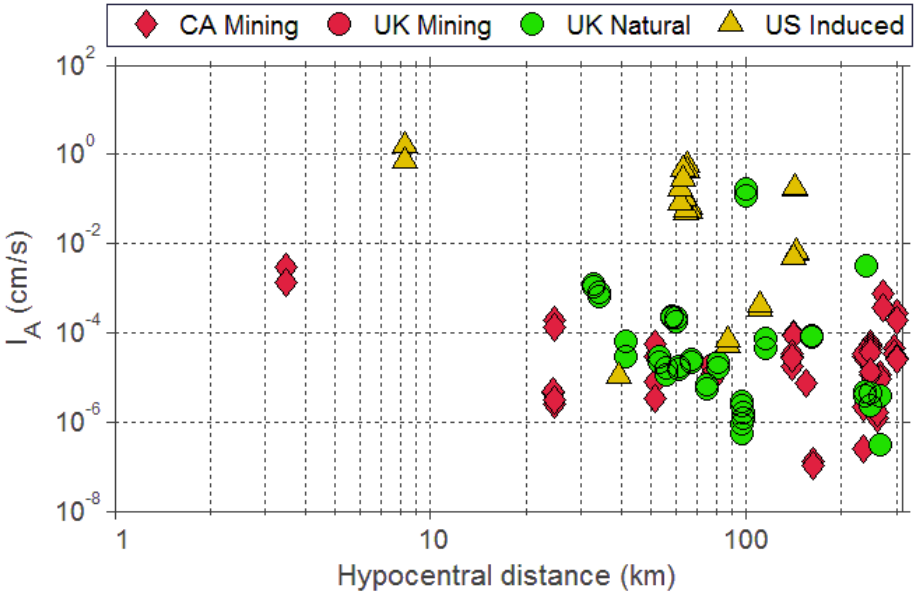
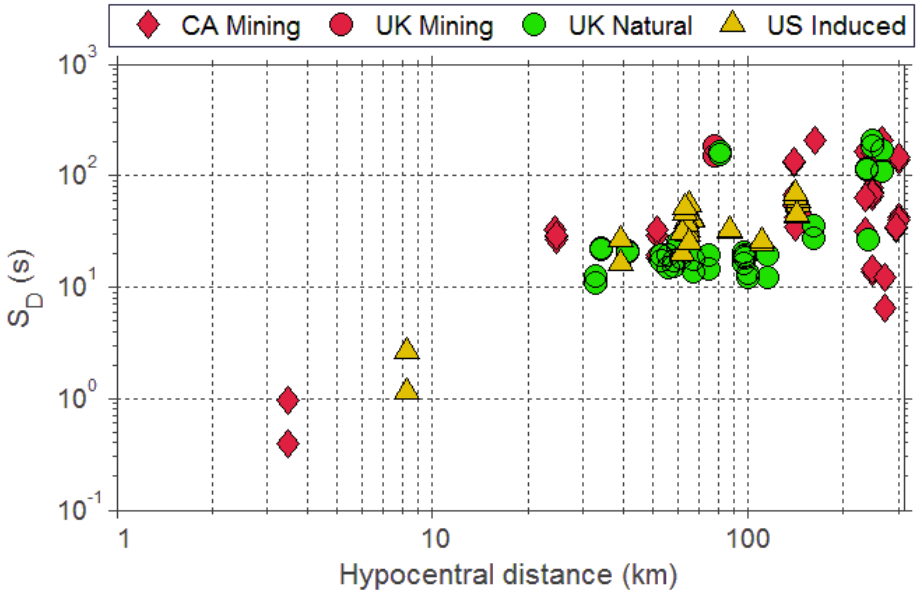
Ground motion characteristics…





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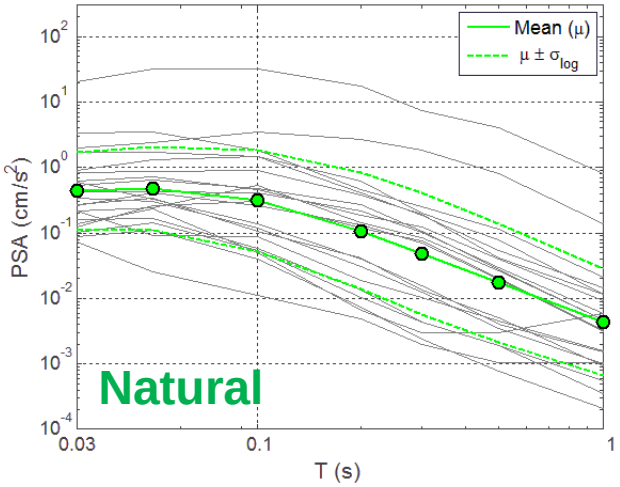
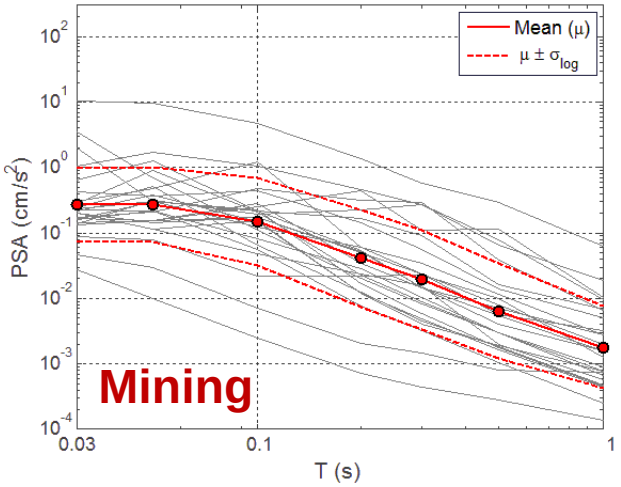
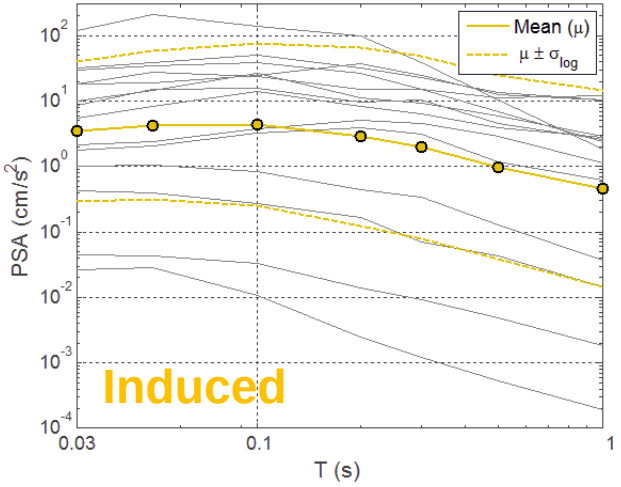
Elastic spectra…







The natural and mining datasets have comparable median spectra. The induced dataset is systematically higher (i.e., 10 times).

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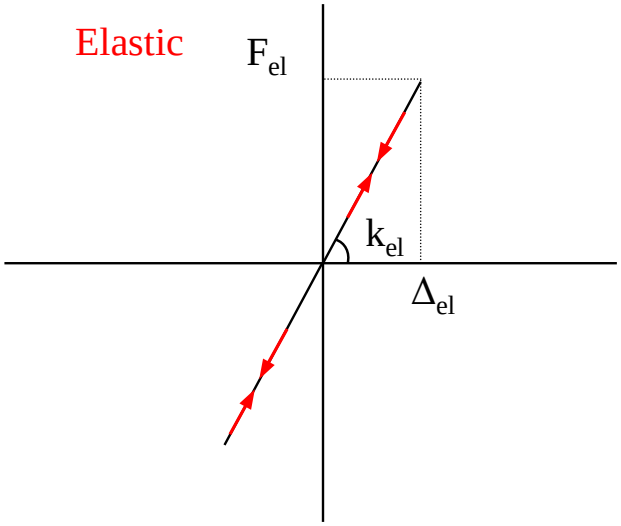
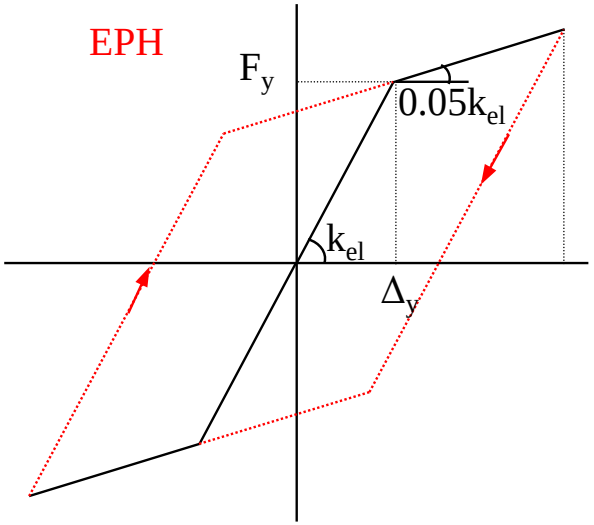
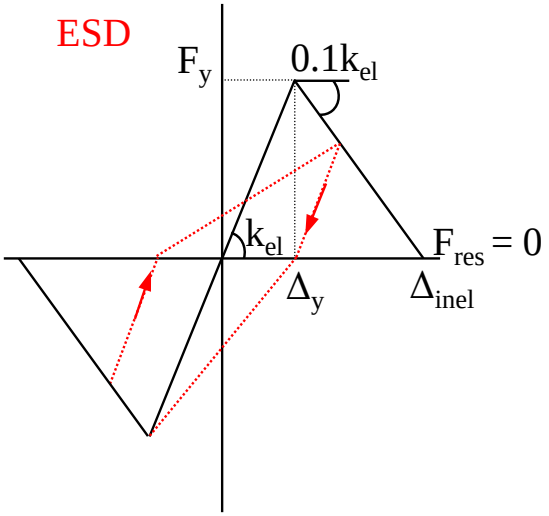
The SDOFs…







constant –R* approach $F_y = F_{el}/R$ $R \in \{1.5; 3.0\}$

$T = \{0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1.0\}$

*see Bazzurro, Sjoberg and Luco, 2004; Iervolino et al. 2010; De Luca et al. 2013

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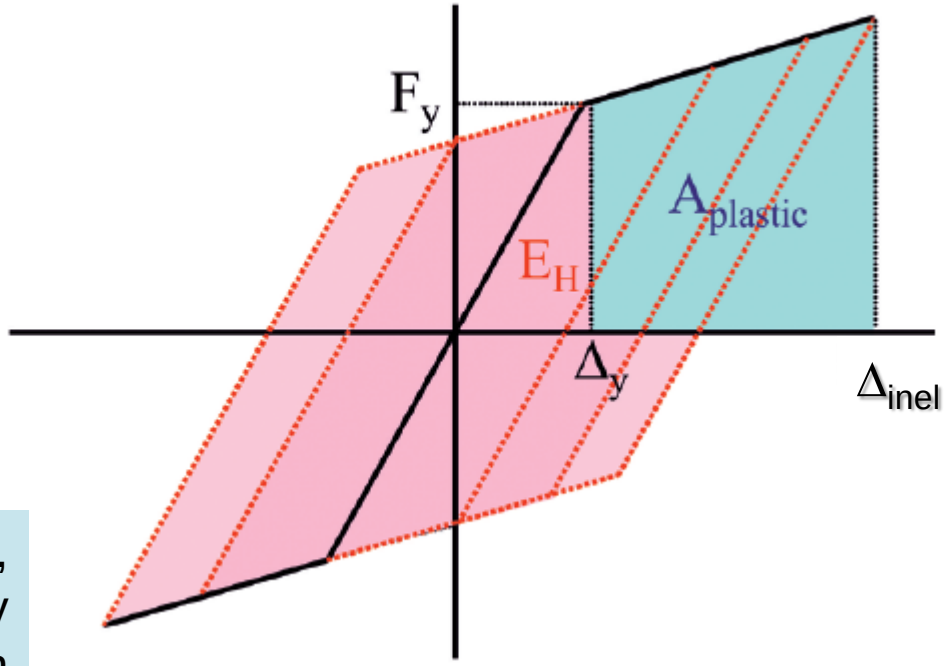
flavia.deluca@bristol.ac.uk

The EDPs…

$$C_R = \Delta_{inel} / \Delta_{el}$$

$$N_e = \left(E_H / A_{plastic} \right) + 1$$



EDPs selected are both “normalized”, so they should not be significantly affected by datasets differences in terms of magnitude and ground motion characteristics.

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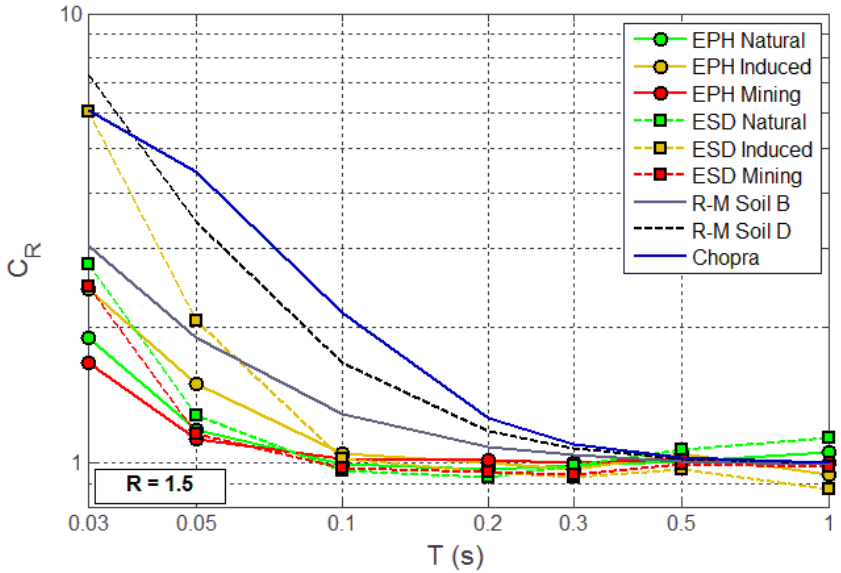
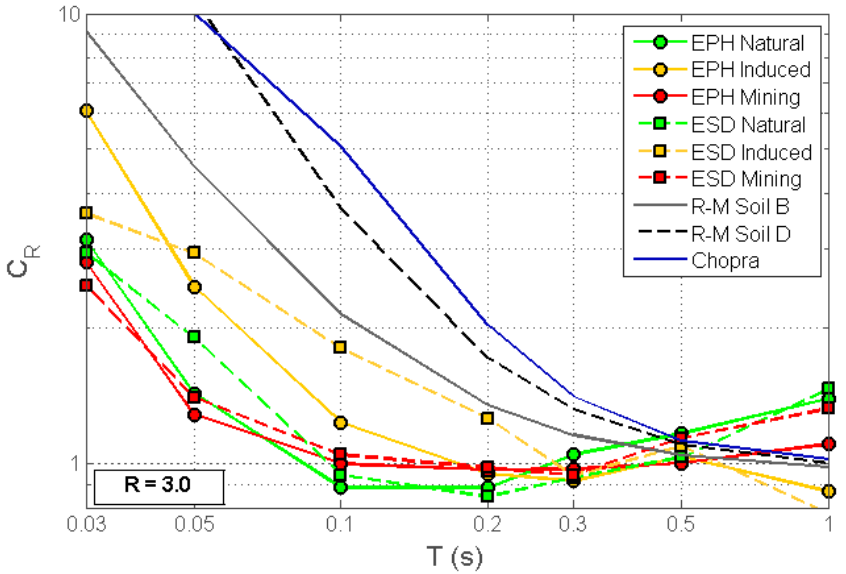
C_R response…





Dataset characteristics (e.g., different average magnitude) seem to affect C_R response for low periods.

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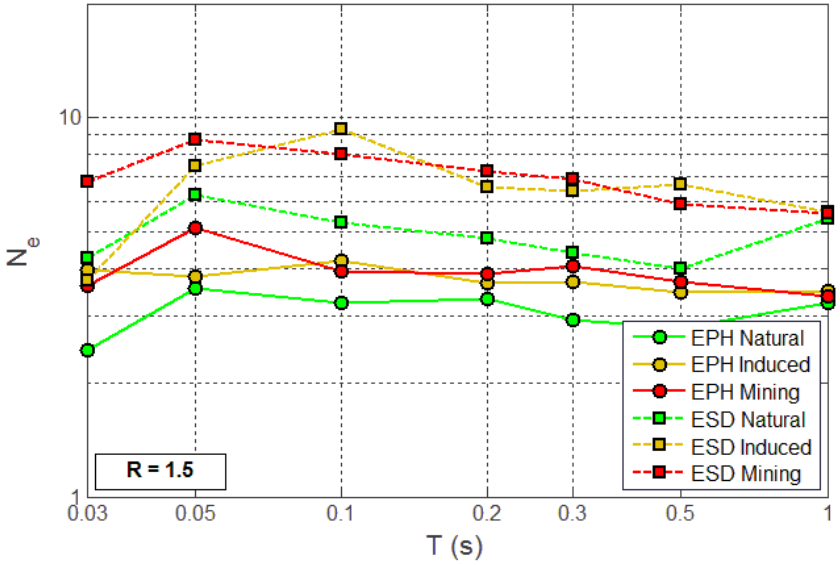
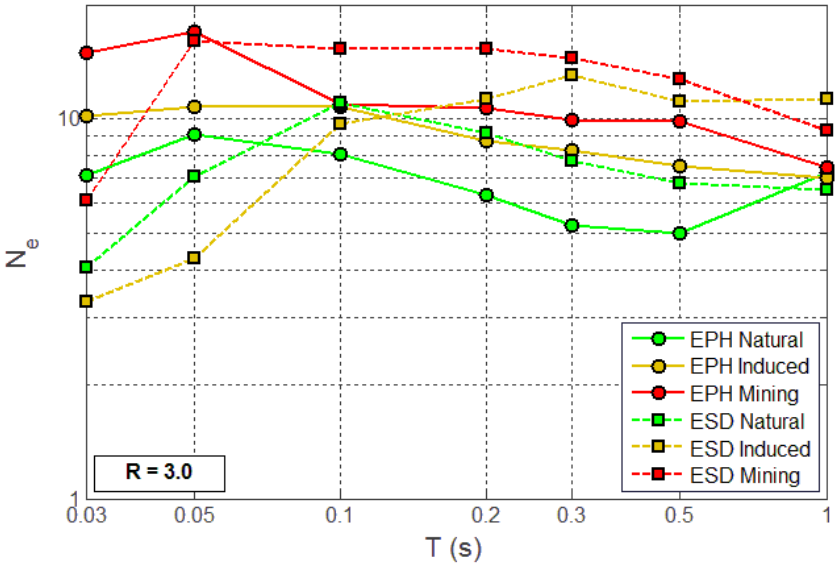
N_e response…



N_e for mining and induced seems systematically higher than N_e for natural (only exception is ESD induced response at 0.03 and 0.05s)



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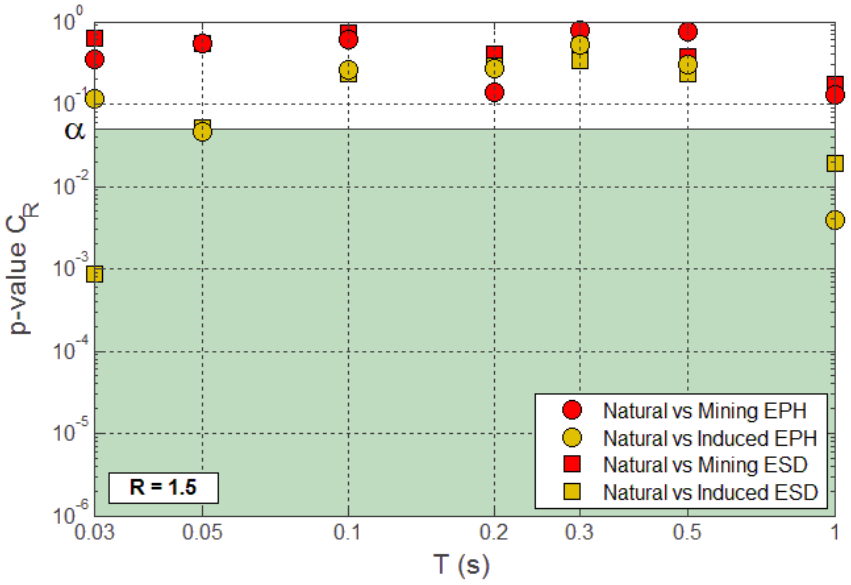
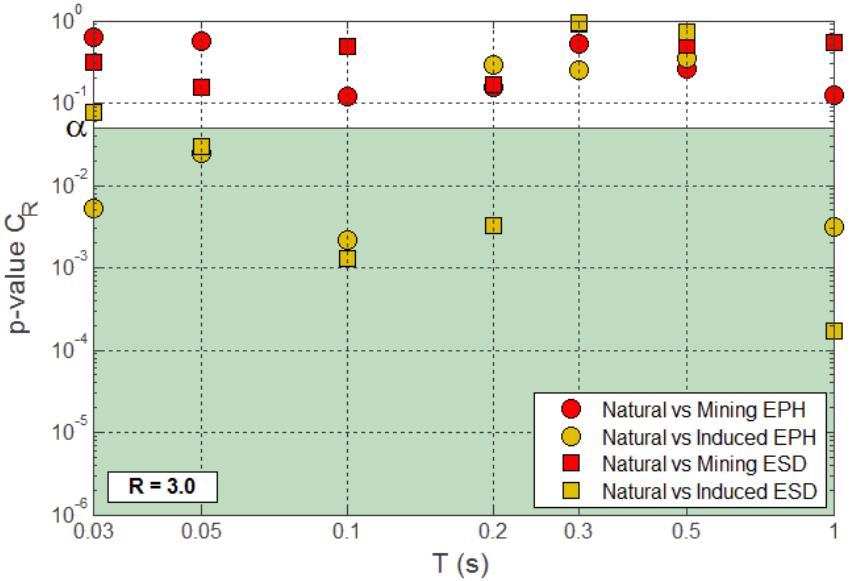
Hypothesis testing…



Aspin-Welch two-tail test, 0.05 significance level (α), hypothesis of log-normal distribution for both C_R and N_e.



Just induced in limited cases seems to have different median C_R response (it is likely due to the influence of M_W on it).

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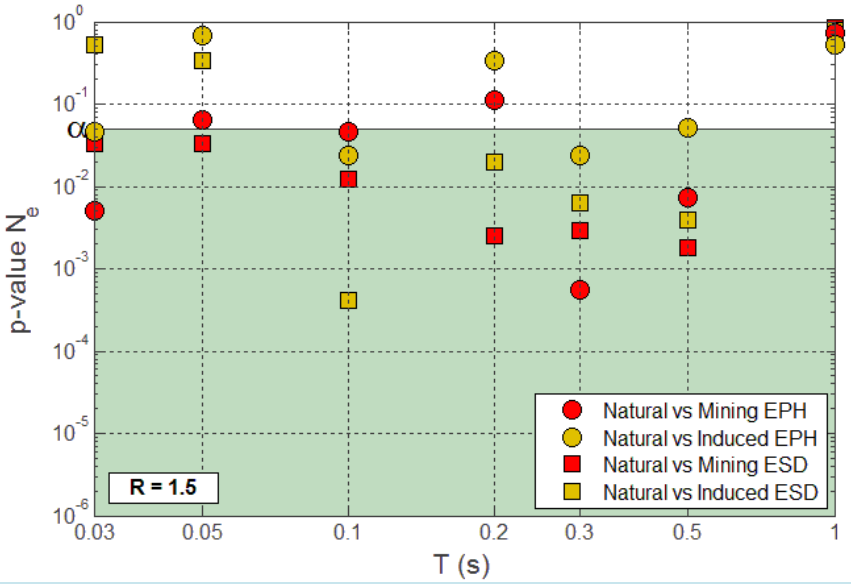
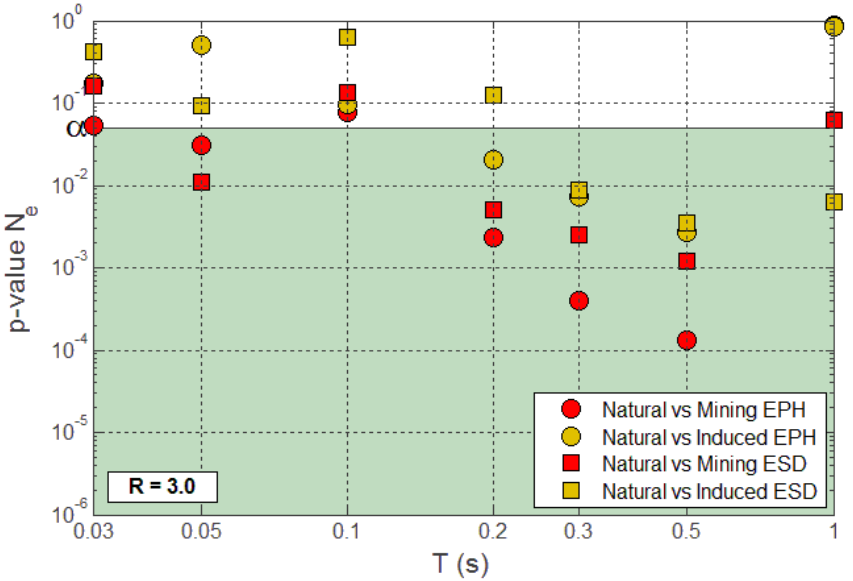
Hypothesis testing…



Significant differences in terms of normalized cyclic response. To some extent expected but to be better investigated.



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flavia.deluca@bristol.ac.uk

Final thoughts & Work in progress…

- Bespoke studies for structural response from human-induced earthquakes can be important for engineering demand parameters accounting for cyclic response explicitly.
- Even if the methodological outline is reasonably robust, need of better quality and more data. In that case comparison with different GMPEs can be of interest and provide further insights.
- Currently using the same dataset to impose spectra compatibility with the same design spectrum to make a "constant-strength" approach.
- Induced seismicity can trigger more and more the attention on modelling efforts to build up robust cyclic models and reliable energy-based capacity for components.

De Luca F, Kythreotis S, Werner M J, Verdon JP (2017). Natural earthquakes as proxies for induced seismic hazard and risk: comparing peak and cyclic inelastic response. Paper ID 1837, 16WCEE, 9-13 January 2017, Santiago (Chile).

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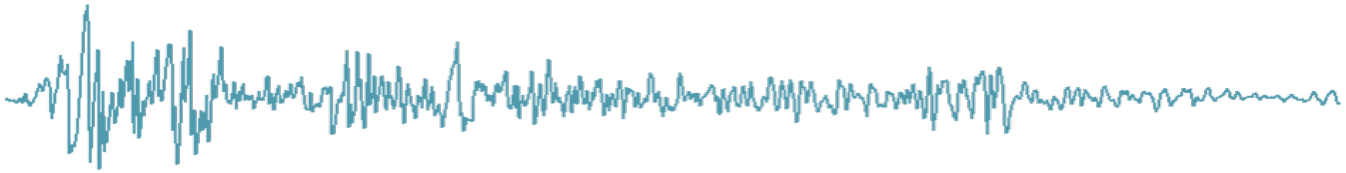
flavia.deluca@bristol.ac.uk

Thanks for your attention



Questions

Flavia De Luca (flavia.deluca@bristol.ac.uk)