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Probabilistic properties of injection induced seismicity – implications for the seismic hazard analysis

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Injection induced seismicity (IIS) is an undesired dynamic rockmass response to massive fluid injections. This includes reactions, among others, to hydro-fracturing for shale gas exploitation. Complexity and changeability of technological factors that induce IIS, may result in significant deviations of the observed distributions of seismic process parameters from the models, which perform well in natural, tectonic seismic processes.

Classic formulations of probabilistic seismic hazard analysis in natural seismicity assume the seismic marked point process to be a stationary Poisson process, whose marks – magnitudes are governed by a Gutenberg-Richter born exponential distribution. It is well known that the use of an inappropriate earthquake occurrence model and/or an inappropriate of magnitude distribution model leads to significant systematic errors of hazard estimates. It is therefore of paramount importance to check whether the mentioned, commonly used in natural seismicity assumptions on the seismic process, can be safely used in IIS hazard problems or not.

Seismicity accompanying shale gas operations is widely studied in the framework of the project "Shale Gas Exploration and Exploitation Induced Risks" (SHEER). Here we present results of SHEER project investigations of such seismicity from Oklahoma and of a proxy of such seismicity – IIS data from The Geysers geothermal field. We attempt to answer to the following questions:

• Do IIS earthquakes follow the Gutenberg-Richter distribution law, so that the magnitude distribution can be modelled by an exponential distribution?

• Is the occurrence process of IIS earthquakes Poissonian? Is it segmentally Poissonian? If yes, how are these segments linked to cycles of technological operations?

Statistical tests indicate that the Gutenberg-Richter relation born exponential distribution model for magnitude is, in general, inappropriate. The magnitude distribution can be complex, multimodal, with no ready-to-use functional model. In this connection, we recommend to use in hazard analyses non-parametric, kernel estimators of magnitude distribution.

The earthquake occurrence process of IIS is not a Poisson process. When earthquakes' occurrences are influenced by a multitude of inducing factors, the interevent time distribution can be modelled by the Weibull distribution supporting a negative ageing property of the process. When earthquake occurrences are due to a specific injection activity, the earthquake rate directly depends on the injection rate and responds immediately to the changes of the injection rate. Furthermore, this response is not limited only to correlated variations of the seismic activity but it also concerns significant changes of the shape of interevent time distribution. Unlike the event rate, the shape of magnitude distribution does not exhibit correlation with the injection rate.

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