GoldSim Modeling Approaches to Earthquake Events

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1. Introduction

An imaginary disruptive event owing to earthquakes whose magnitude are over a certain limitation has been commonly considered for safety assessment of geologic radioactive waste repositories with earthquake scenario.[1] Earthquakes are assumed to result abnormal critical events like near-repository well drilling human intrusion scenarios e.g., an increase of groundwater flow and a direct connection to fast preferential pathways to the biosphere of the repository system providing the shortest nuclide release pathway. In such scenario we roughly and generally used the assumption that only two principal parameters, the magnitude of the earthquake and the distance between a repository and its epicenter are enough to characterize earthquakes, and that they follow statistical behaviors of the distributions; a log-uniform distribution for the magnitude, e.g., ~uniform[5.0,8.0] and a triangular distribution, e.g., ~triangular[0, 5, 25]km for the distance, respectively, which do not have any specific evidence yet for the time being though. And earthquake events used to be assumed to occur based on a simple Poisson distribution at a random time interval.

In such case magnitude-to-distance ratios (M/D) over some value for a flow increase in the geological groundwater pathways and/or direct connection to the shortest pathway to the biosphere when M > threshold magnitude is postulated in view of the long-term safety that might be disruptive enough to reduce the performance of the repository. This model has been implemented to the GoldSim module and utilized for safety assessments of the various type of repository system as shown in Fig.1.

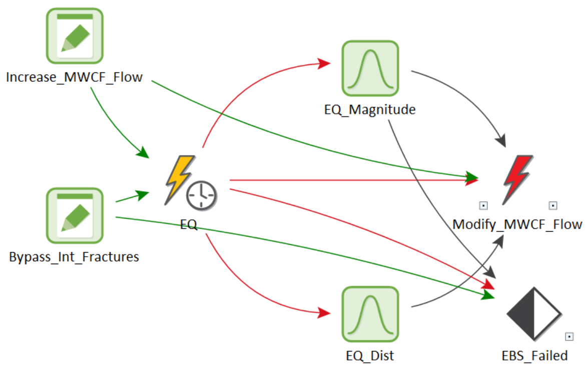


Fig. 1. GoldSim module for earthquake disruptive event.

In Fig. 1, the magnitudes and distances are generated by the distributions assumed and the occurrence of earthquakes are also assumed to follow a log-uniform distribution, which seem rather appropriately chosen in view of historical earthquake recordings.

A different approach for the case that the magnitudes and frequency rates of earthquakes are assumed to mimic and follow the time series data recorded during the past years on the Korean Peninsula, even though the distances between the repository and epicenters still follow a simple uniform distribution has also been modeled.[2]

In Fig. 2, a GoldSim module implemented for such an earthquake scenario is shown, in which the occurrence rates of earthquakes and their magnitudes are generated by the time series data.

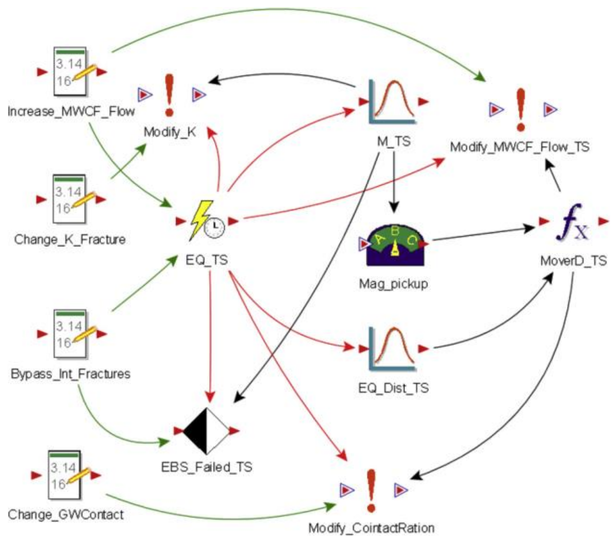


Fig. 2. GoldSim module for earthquake events that follows the past time-series data.

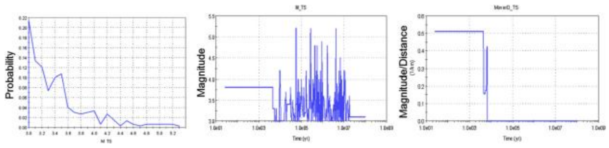


Fig. 3. PDF for magnitudes obtained from the past time-series earthquake measurements (left), simulated earthquakes (center), and calculated M/D (right).

In this model, since the occurrence of earthquakes between a magnitude of e.g., 3 and 5.5 is quite high, which necessarily requires a quite long simulation, for this study, a reduced frequency by a factor of 10^{-4} was temporarily used. Then, from the observed magnitudes and occurrence rates, a probabilistic distribution function is generated, as shown in Fig. 3, in which simulated M/D ratios are also illustrated.

2. Bayesian Updating

Although reliable estimation of the distributions expressed as probability density functions for input parameters needs large amount of measured data, in most cases, especially in the safety assessment of the repository which is typically associated with long time span, observed data are usually limited resulting conventional probabilistic calculations rather uncertain. In the earlier study, an imaginary disruptive event due to earthquakes was considered. The occurrence rates of earthquakes are modeled to be Bayesian updated sequentially in the study.[3-6]

In such case avoiding relying on such limited data available and/or some historical prior knowledge, a posterior distribution that could result from those prior distribution multiplied by supplementary beliefs and judgment regarding the parameter as well as recent measurements, as represented in Eq. (1).

$$p(\vec{\theta}|H_i, I, D) = \frac{p(D|\vec{\theta}, H_i, I)}{p(D|H_i, I)} \cdot p(\vec{\theta}|H_i, I) \propto \mathcal{L}_\theta(H_i) \cdot p(\vec{\theta}|H_i, I) \quad (1)$$

which means the posterior is proportional to the likelihood times the prior showing the posterior has all the information from prior beliefs and data as an evidence, where $\vec{\theta}$ = parameter vector, H_i = hypothesis or Model, I = information, D= data.

Prior probability, $p(\vec{\theta}|H_i, I)$ is based on the output from previous observations and general historical belief and the likelihood, $\mathcal{L}_\theta(H_i)$ that represents a probability of obtaining data, D, for a given prior information I and a parameter set, $\vec{\theta}$.

For Bayesian updating, despite of its advantage, practical application might be very limited due to difficulty to get a posterior distribution easily or analytically except e.g., conjugate prior distributions.

That is the reason Markov Chain Monte Carlo (MCMC) sampling algorithm widely used is adapted to the study.

In fig. 4, realizations of three sequential Bayesian updatings for earthquake frequency are illustrated.

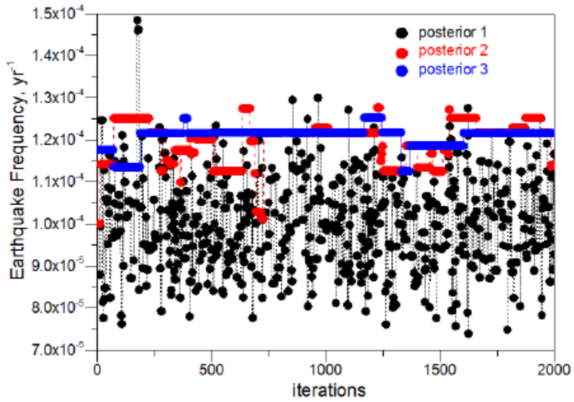


Fig. 4. Realizations of sequential Bayesian updating by MCMC for earthquake frequency.

3. Power Law Approach

In seismology it has been well known that Gutenberg-Richter law represents well the relationship between the magnitude of the earthquake and the total number of earthquakes in any seismogenic region which is given by:

$$\log N = a - bM \text{ or } N = 10^{a-bM} \quad (2)$$

where N = number of events having a magnitude $\geq M$, a, b = constants, which follows the Pareto distribution.

The probabilistic distribution of Eq. (2), which theoretically predicts magnitudes with no upper limit. However, realistically there is some limit on the upper bound of earthquake magnitudes in a region, which introduces bounded Gutenberg-Richter Recurrence Law as shown in Fig. 5.

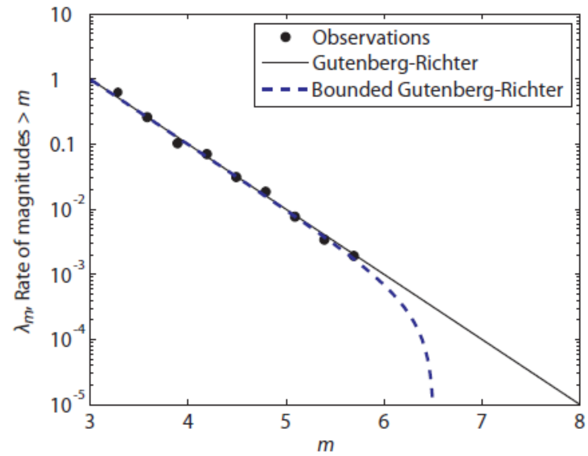


Fig. 5. Example for bounded Gutenberg-Richter Law for the magnitude and earthquake occurrences.

This modified model has also been implemented to the GoldSim module and utilized for safety assessments of the various type of repository system as shown in Figs. 6 and 7 and some sample calculation results are shown in Figs. 8 and 9.

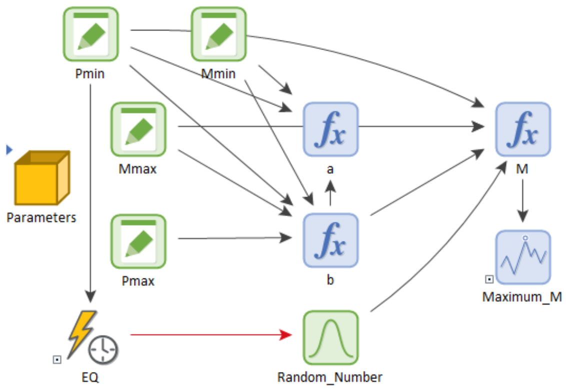


Fig. 6. GoldSim implementation of the Gutenberg-Richter Law.

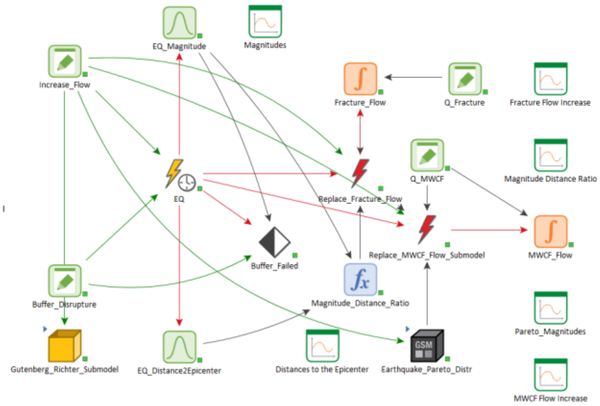
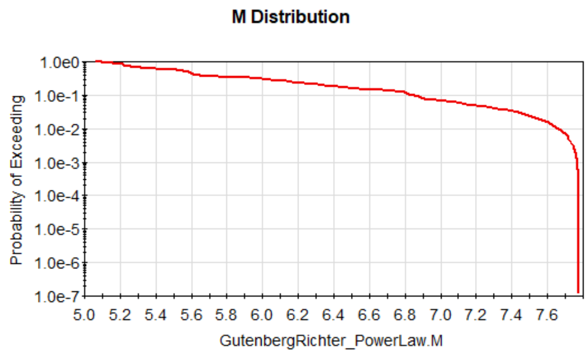
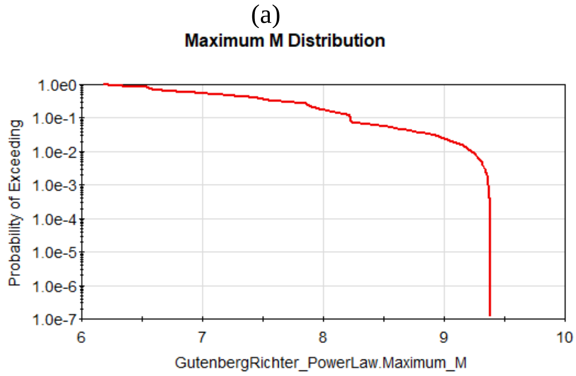


Fig. 7. GoldSim implementation of earthquake scenario for safety assessment of the radioactive waste disposal repository.



(a)



(b)

Fig. 8. Sample results for the relation between the earthquake magnitudes and the probabilities exceeding the magnitudes. (a: M distribution; b: maximum M, the largest observed magnitude over the lifetime)

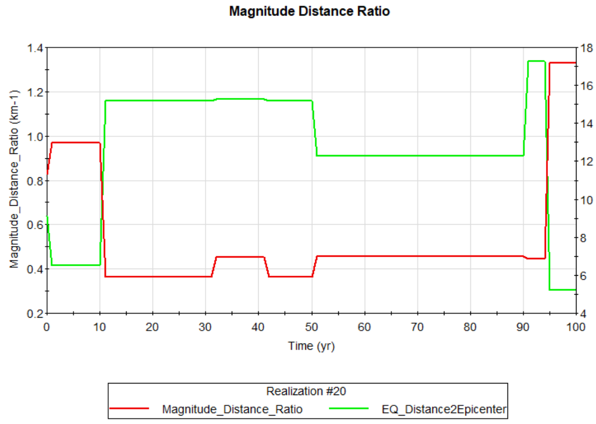


Fig. 9. M/D ratio computed by GoldSim module for Gutenberg-Richter Law with assumption data.

4. Conclusive Remarks

Earthquakes are one of the most critical disruptive events as well as human intrusion that should be considered for abnormal radionuclide scenario in and around the radioactive waste repository.

Through the study a couple of GoldSim modules for evaluation of an imaginary disruptive event owing to earthquakes whose magnitude are over a certain limitation was introduced, which could be usefully applied to safety assessment of the repository.

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