

Stochastic approach of location-independence earthquake disaster risk estimation for mercury waste landfill

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INTRODUCTION

Mercury has unique characteristics like liquid under ambient condition and has been used in industry and society. Due to high toxicity and hazards to human bodies and the environment, international efforts to regulate and decrease mercury use has been paid [1]. In this context, the Minamata convention on mercury was agreed in 2013 and made effective on 16th Aug. 2017. The collection of mercury used in industry and society is requested and long-term safe storage of collected mercury is also necessary in near future. Mercury storage in engineered landfill sites is one option in terms of cost and environmental safety. However, environmental risk of mercury landfill disposal should be carefully assessed, in particular earthquake regions like Japan. Seismic impact on landfill site safety or durability has been concerned [2]. For example, earthquake-induced displacement of landfilled wastes were affected by the amplitude (peak acceleration) and frequency content (mean period) of the design rock motion and the dynamic response characteristics of the landfilled wastes [3]. In addition, local geological condition of a landfill site might also play a significant role in the seismic response of a landfill [4]. In this sense, site selection of landfill sites is important and should be socially concerned [5]. Landfill site selection is a complex task in which various factors should be considered [6]. One of important factors for site selection or screening is Not-In-My-Backyard (NIMBY) syndrome, in other word, public opposition toward landfill site construction [7-8]. According to strongly negative attitude toward site screening, pre-assessment of environmental risk for mercury final disposal in specific candidate sites might cause public confusion and/or miscommunication. On the other hand, geological information of potential landfill sites is necessary for appropriate assessment of earthquake-induced environmental risk of mercury landfill disposal. In order to overcome this paradoxical problem, this study developed a new method for environmental risk estimate of location-independence earthquake disaster risk. The purpose of this work is to test a stochastic approach to build a methodological framework for location-independence risk estimation. As the first step, this study considered mercury temporal storage on the ground near the final landfill site because mercury stabilization before landfill disposal is necessary.

METHODS

Risk scenario of mercury release to the environment caused by big earthquake

This study considered a risk scenario of mercury release event to the environment. In this scenario, mercury storage facility on the ground will be hit by a big earthquake. Owing to facility destruction, mercury containers will be transferred unintentionally to the environment. Owing to container damages, mercury will be emitted from the containers by rain water penetration. In this article, the amount of released mercury from the containers would be reported.

Stochastic approach to estimate the probability of big earthquake hit to mercury storage facility

As mentioned in Introduction section, this work does not take any site-specific scenario for mercury risk estimation. According to USGS Earthquake Catalog database [9], earthquake event with magnitude more than 6.5 were screened and then the event data (location, hypocentral depth, and magnitude) were extracted in the area at 130-135 degrees east longitude and 30.5-40.1 degrees north latitude. Time period of data extraction was 120 years from Jan 1900 to Mar 2020. The locations of screened earthquake event are shown in Fig 1. Appropriate statistical distributions of hypocentral depth, magnitudes, and distances from hypocentral location to capital cities of all prefectures in Japan were determined based on Bayesian

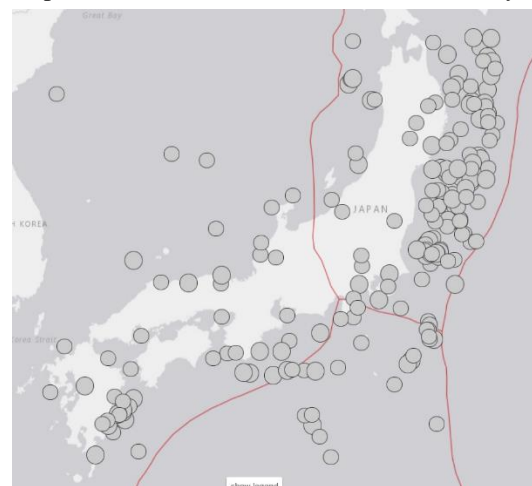


Fig. 1 Locations of earthquake events with more than M6.5 extracted from Jan 1900 to Mar 2020

information criterion (BIC). Using these statistical distributions, the probability of an earthquake event at specific time and location can be predicted stochastically as well as the earthquake magnitude and distances to specific location. According to the earthquake magnitude and distance data, peak ground acceleration (PGA), peak ground velocity (PGV), and their distance attenuations [11] were also possible to predict stochastically. To validate predicted PGV, database of J-SHIS earthquake hazard station [10] were used. PGVs with 3 % and 6 % of 30-year exceedance probabilities and PGVs with 2 %, 5 %, 10 %, and 39 % of 50-year exceedance probabilities for all prefectural capital cities in Japan were extracted from J-SHIS database and local averages of these PGVs were calculated. These averages were compared with those predicted by this method for validation.

Stochastic approach to estimate the destruction probability of mercury storage facility caused by big earthquake hit

This work used empirical response spectrum with 5 % distance attenuation, proposed by Umemura [12], of each earthquake event. Even when acceleration response spectrum of an earthquake event exceeds maximum durable acceleration response spectrum determined by limit horizontal strength calculation, it does not result in inevitable destruction of mercury storage facility. According to destruction survey of houses and buildings hit by Southern Hyogo earthquake in 1995, building destruction ratio followed normal distribution of earthquake strength, which was described as the ratio of PGA to gravity acceleration [13]. This statistical distribution was used to predict the probability of facility destruction by an earthquake hit in this study.

Stochastic approach to estimate mercury release from storage containers to the environment via rain water penetration

135-year precipitation data in Tokyo from 1880 to 2015 were used for the Stochastic approach to estimate mercury release from storage containers to the environment. Data shows that the precipitation follows normal distribution as shown in Fig. 2. When mercury sulfide in the storage containers contacts with water penetrated from cracks on container surface, which was caused by the earthquake hit, mercury is dissolved in water and transfers to outside along with water flow and finally reached to the environment. The cumulative amount of released mercury and its probability were calculated for mercury risk assessment. In this article, however, mercury risk will not be reported due to page limitation.

RESULTS AND DISCUSSIONS

Optimum statistical distributions of earthquake hypocentral depth, magnitudes, and distances from

hypocentral location to capital cities of all prefectures in Japan

This study tested three statistical distributions, lognormal, gamma, and Weibull distributions, to find the most appropriate distributions based on BIC. The results are shown in Fig. 3 for hypocentral depth, Fig. 4 for magnitude, and Fig. 5 for distances to prefectural

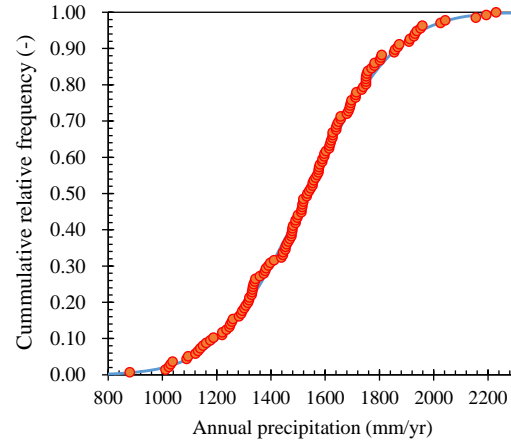


Fig. 2 Cumulative relative frequency of the annual precipitation for 135-year from 1880 to 2015

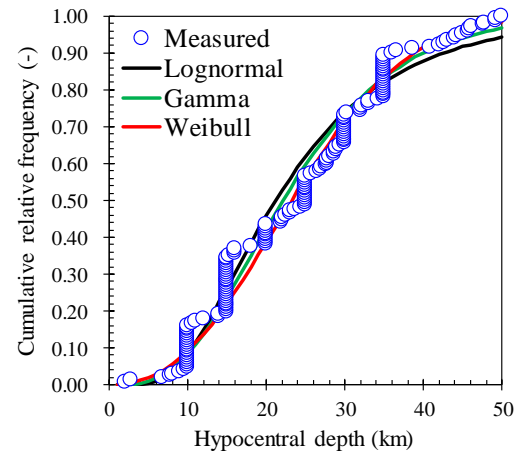


Fig. 3 Statistical distributions of hypocentral depth

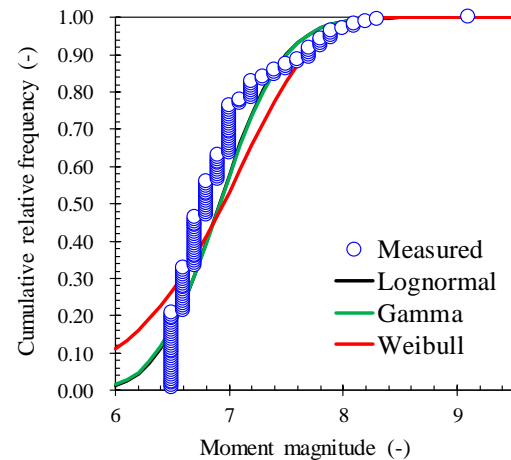


Fig. 4 Statistical distributions of moment magnitude

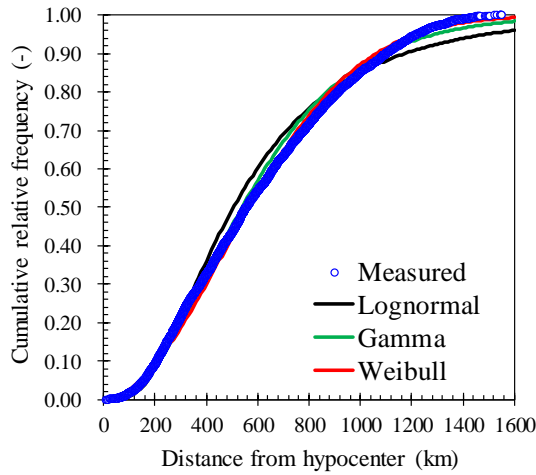


Fig. 5 Statistical distributions of distance to the hypocenter

capital city, respectively. The most appropriate statistical distribution of hypocentral depth and magnitude was identified lognormal distribution. Weibull distributions was the best for the distances to prefectural capital cities.

The validation results using PGVs with 3 % and 6 % of 30-year exceedance probabilities and PGVs with 2 %, 5 %, 10 %, and 39 % of 50-year exceedance probabilities are shown Fig. 6. Although predicted PGVs at many prefectural capital cities agree with those referred from J-SHIS database [10], large underestimation of PGVs by this method are found in some cities near pacific oceans. These cities are expected to be hit by Nankai and Tokai Trough Earthquakes in the future due to periodical earthquake events. As mentioned in Methods section, this study used earthquake event data since 1900, not included periodical earthquake events before 1900. It might have caused this underestimation. Therefore, the stochastic approach developed in this study needs further improvement to include highly-probable periodical earthquake events like Nankai and Tokai Trough Earthquakes.

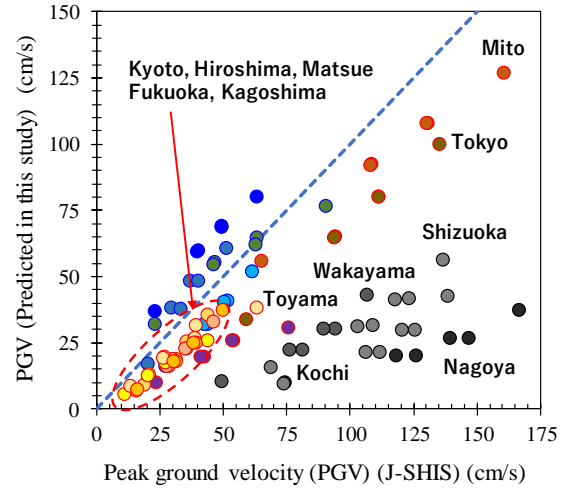


Fig. 6 Comparison of peak ground velocity between the predictions of this study and J-SHIS database [10]

Stochastic estimation of 100-year exceedance probabilities of earthquake events with seismic intensity class of 5 or more.

When mercury storage facility is built anywhere in Japan, 100-year exceedance probabilities of earthquake events with seismic intensity class of 5 or more are shown in Fig. 7. In particular, class 7 earthquake event is concerned due to its high probability of facility destruction. This study estimated that 25-year exceedance probabilities of class 7 earthquake events was 0.83 %. It was increased to 1.7 % for 50-year exceedance probability and 3.3 % for 100-year exceedance probability. It is considered that 25 years or longer use of mercury storage facility on the ground was not realistic because this facility would be used for mercury stabilization (conversion to mercury sulfide) and temporal storage before final disposal in the landfill site. In this sense, 3.3 % for 100-year exceedance probability might not be necessary to consider facility destruction risk. On the other hand, the stochastic model of this study also suggests that 0.83 % probability of class 7 earthquake hit should be concerned when the facility is used for 25 years.

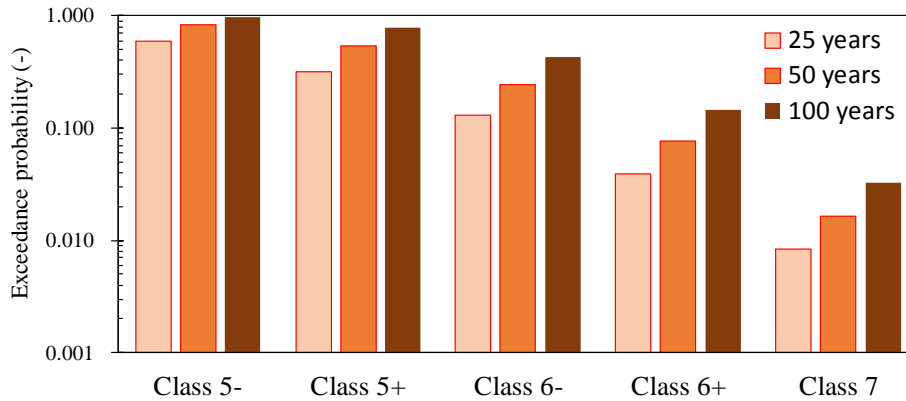


Fig. 7 Exceedance probabilities of earthquake events with seismic intensity class of 5 to 7

100-year mercury release from storage containers to the environment via rain water penetration

When mercury containers are transferred unintentionally to the environment after the destruction of mercury storage facility, mercury will be released from the container for long term. This study considered 100 years mercury release. Cumulative relative frequency of expected total release of mercury for 100 years is shown in Fig. 8. 75 percentile range of mercury release is 0.138-41.5 mg-Hg. The median is 13.3 mg-Hg. When 95 percentile range is considered, the maximum is only 50.4 mg-Hg. Because the stochastic model of this study seems to overestimate the destruction probability of mercury storage facility, even 50.4 mg-Hg release might be overestimated. Therefore, this study concludes that accidental mercury release from mercury storage facility by large earthquake hit gives negligible risk to the environment. However, it should be noted that this study assumed that mercury sulfide, in containers transferred out of the facility, was stable in the environment. When mercury sulfide is converted to other mercury species like mercury oxide by chemical or biological reactions, several orders of magnitude larger leaching rate of mercury to penetrated rain water is expected. Further researches are necessary to conclude mercury risk more appropriately.

CONCLUSIONS

This study developed the stochastic model of location-independence earthquake disaster risk estimation for mercury ground storage before final landfill disposal. This study concludes that accidental 100-year cumulative release of mercury by the destruction of mercury storage facility hit by a large earthquake is 50.4 mg-Hg or less. Although it might be negligible in terms of environmental risk, further research is necessary for more reliable estimation.

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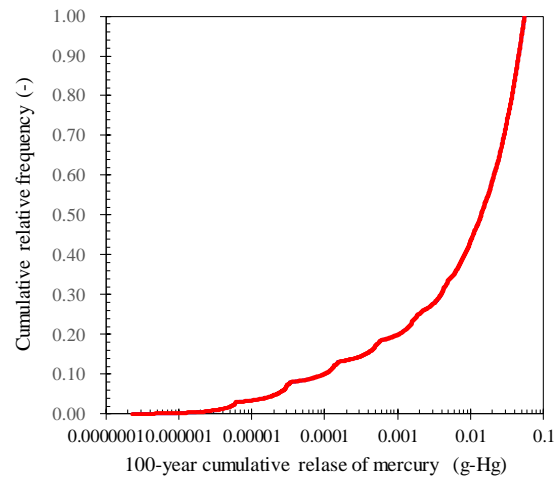


Fig. 8 100-year cumulative release of mercury

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