Development of a Seismic Risk Assessment System for Low and Intermediate Level Radioactive Waste Repository - Current Status of Year 1 Research - 11393

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ABSTRACT

The purpose of this study is development of a seismic risk assessment system for a low and intermediate level radioactive waste repository. For the performing of this study, this research considers four major parts: seismic hazard analysis, seismic fragility analysis, seismic risk analysis and assessment of radiation dose. Evaluation response spectrum for seismic risk assessment of low and intermediate repository system is developed in this study through a seismic hazard analysis. For the seismic fragility analysis, selection of major structures, systems and components (SSCs) which can affect the seismic safety of a radioactive waste repository was performed. After that, a numerical analysis model for selected SSCs is developed. Using the numerical model seismic fragilities are evaluated. For the seismic risk analysis, fault trees and event trees for a seismic event are developed and accident scenario analysis performed. For the evaluation of radiation dose, atmospheric and geologic data for the radioactive waste repository site are collected. Dose conversion factor was considered and leakage rate for accident scenario is determined and source term is evaluated. Finally using the result of seismic risk, radiation doses caused by seismic event can be determined.

Key Words: Seismic Risk, Hazard analysis, Fragility analysis, Radiation dose, evaluation response spectrum

INTRODUCTION

The purpose of this study is development of a seismic risk assessment system for low and intermediate level radioactive waste repository. For the performing of this study, this research considers four major parts; seismic hazard analysis, seismic fragility analysis, seismic risk analysis and assessment of radiation dose. Evaluation response spectrum for seismic risk assessment of low and intermediate repository system is developed in this study through a seismic hazard analysis. For the seismic fragility analysis, selection of major structures, systems and components (SSCs) which can affect to the seismic safety of radioactive waste repository was performed. After that, a numerical analysis model for selected SSCs is developed. Using the numerical model a seismic fragility analysis is evaluated. For the seismic risk analysis, fault trees and event trees for seismic event are developed and accident scenario analysis performed. For the evaluation of radiation dose, atmospheric and geologic data for the radioactive waste repository site are collected. Dose conversion factor was considered and leakage rate for accident scenario is determined and source term is evaluated. Finally using the result of seismic risk, radiation dose caused by seismic event can be determined.

This paper is only the 1st year preliminary results among the total project scope. This paper considered as evaluation response spectrum, selection of major SSCs and sample seismic analysis results, collected atmospheric and geologic data and overview of numerical program for seismic risk assessment for radioactive waste repository. For the generation of evaluation response spectrum for seismic risk assessment of radioactive waste repository, seismic hazard analysis for the target site in Korea was performed. Using the seismic hazard curve a uniform hazard spectrum was developed. The

30 artificial acceleration time histories which satisfy uniform hazard spectrum were generated and seismic response analysis performed according to the target ground condition. Through this study, an evaluation response spectrum for seismic risk analysis of the Silo which is most important structure in the radioactive waste repository system and located underground was developed. For the selection of target SSCs, all SSC list in the low and intermediate radioactive waste repository system was investigated. A repository cavern (silo), operation cavern, construction cavern and surface structure were selected for a seismic fragility analysis. A numerical model for surface structure was developed by using a finite element method (FEM). For the collection of atmospheric and geologic data for target radioactive waste repository system, atmospheric stability, wind speed variation, population distribution of target site and geologic data were gathered and investigated. Finally, an integrated numerical analysis program for seismic risk assessment for low and intermediate radioactive waste repository system was developing. For this purpose, fault tree and event tree editor and hazard curve and fragility curve input editor were developed. Through this study, seismic risk for low and intermediate level radioactive waste repository system can be determined by probabilistic method.

OVERVIEW OF RESEARCH PROJECT

The research project about 'Seismic risk assessment system for medium and low level radioactive waste repository' consists as major four parts. A structure of research project is shown in Figure 1. As shown in Figure 1, risk analysis contain a seismic hazard analysis part because the results of seismic hazard analysis should be used for seismic analysis of the three parts are fragility analysis, risk analysis and evaluation of radiation dose. This research will be carried to 3 years and is now almost at the middle of the whole research period. In the case of fragility analysis, selection of structure, system and components for related in safety of waste repository system is a task for 1st year research. In the second year for fragility analysis, development of numerical model for selected structure, system and components and performing a seismic analysis. The last year, fragility analysis for structure, system and components are performing and for the fragility analysis, failure mode and criteria should be determined preferentially. In the case of risk analysis, a development of evaluation response spectrum for waste repository system is a first year task. A development of fault tree and event tree and performing an accident scenario analysis are 2nd year research project. In the third year, development of seismic risk assessment method and finally seismic risk assessment is a target of research. For the performing an evaluation of radiation dose, analysis of atmosphere and geologic data and determination of a dose conversion factor should be performed. In the second year, leakage rate for accident scenario and source term evaluation are performed. Finally, radiation dose will be determined using a seismic risk evaluation results. A user-friendly computer program for seismic risk assessment for radioactive waste repository system will be developed through this study also.

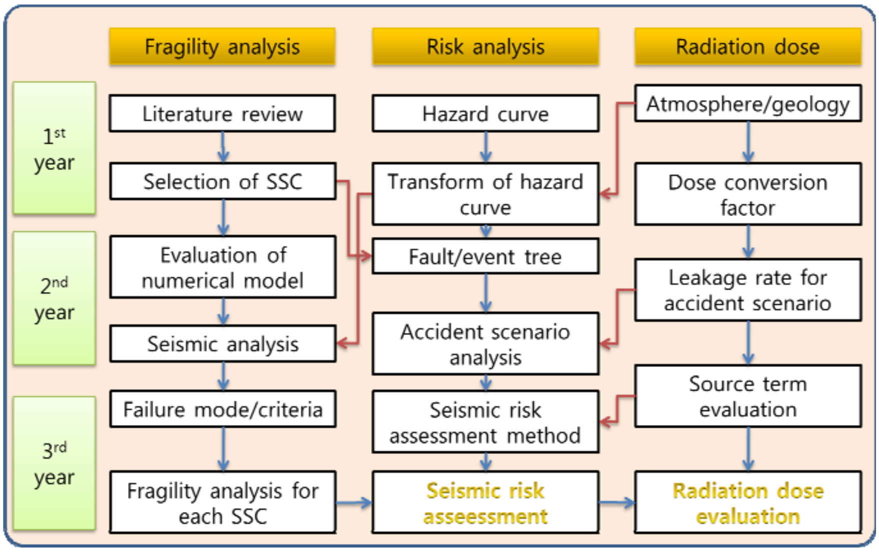


Fig. 1. A procedure of development for Seismic Risk Assessment of Radioactive waste Repository System

Fragility Analysis

For the performing a fragility analysis, safety related structures, systems and components were selected. The low and intermediate radioactive waste repository system was consist ground structure and underground structure. A ground storage system was selected for seismic risk assessment among the ground structures. In the case of underground structures, vertical cavern, operation cavern, construction cavern and underground repository cavern were selected for seismic risk assessment. The most important structure in the radioactive waste repository system is an underground repository cavern (SILO). For a numerical analysis for seismic input motion, numerical model for ground storage system and underground cavern were developed by using commercial numerical program. Now seismic analysis is performing about the target selected ground and underground structures.

Risk Analysis

For the performing a seismic risk analysis of radioactive waste repository system, seismic hazard analysis was carried out. The seismic hazard analysis for radioactive waste repository system was already performed by a company but the result of seismic hazard analysis defined as ground surface motion. But for the seismic risk analysis for underground cavern, evaluation response spectrum for the location of underground structure should be defined by based on the result of seismic hazard analysis. The procedure and the results of development for evaluation response spectrum are shown in this paper as below.

Radiation Dose Evaluation

For the evaluation of radiation dose caused by seismic event, atmospheric condition and geologic condition of target radioactive waste repository system were analyzed. Through this study, public and workers risk can be evaluated. In this study, death, disease, genetic damage and economic loss should be determined as public risk. In the case of 1st year, atmospheric stability, wind speed and population per distance were investigated.

DEVELOPMENT OF EVALUATION RESPONSE SPECTRUM

An evaluation response spectrum for seismic risk assessment of radioactive waste repository in Korea was developed in this study. For the development of evaluation response spectrum, a seismic hazard analysis, evaluation of uniform hazard spectrum, generation of artificial time history acceleration and site response analysis were performed. For the performing a seismic hazard analysis, a seismic source model and input parameters were selected. The Gutenberg Richter a-value and b-value, moment magnitude and focal depth were decided. Attenuation equation was decided as midcontinent of Toro. Using the seismic source, input parameters and attenuation equation, a seismic hazard curve for base rock site was developed through the seismic hazard analysis. The seismic hazard curve should be transformed for underground structure. A uniform hazard spectrum was generated by using the seismic hazard curve for generation of artificial acceleration time history. The 30 artificial seismic acceleration time histories were generated based on the uniform hazard spectrum by using P-CARES program. A seismic response analysis was performed of 30 artificial acceleration time histories for target radioactive waste repository site for the development of evaluation response spectrum. Finally, an evaluation response spectrum for seismic risk assessment of radioactive waste repository was proposed.

Development of Seismic Hazard Curve

For the development of a seismic hazard curve, a probabilistic seismic hazard analysis (PSHA) was performed. An area seismic source was selected for the PSHA in Korea. The relation of magnitude of seismic events to the return period can be represented by Gutenberg-Richter relation as shown in equation (1).

$$\log N = a - bM \quad (1)$$

Where, a and b are a constant value at the same seismic source. Various methods can be used for the determination of maximum earthquake magnitudes, otherwise generally previous maximum earthquake magnitudes plus 0.5 can be used as a maximum earthquake magnitude. In this study, a maximum earthquake magnitude was determined as 6.7±0.5 according to the advice of an expert panel. An epicentral distance was considered as 10±5km. All the input parameters considered in this study are summarized in Table 1.

Table 1. Input parameters for PSHA

Parameter	Value
a-value	5.5 ± 0.5
b-value	0.8 ± 0.1
M_{Max}	6.7 ± 0.5
Focal depth (km)	10 ± 5

An attenuation relation is one of the important factors in performing a PSHA. In Korea there is no strong earthquake record so it is very difficult to determine a reasonable attenuation equation, therefore an attenuation equation which was based on the central eastern area of the United States was used for Korea. In this study, an attenuation equation developed by Toro et al. (1997) was selected for PSHA for Wolsung radioactive waste repository system in Korea as shown in equation (2). Input parameters for the attenuation equation are summarized in Table 2.

$$\ln Y = C_1 + C_1(M-6) + C_3(M-6)^2 - C_4 \ln R - (C_5 - C_4)\max\left(\ln\left(\frac{R}{100}\right), 0\right) - c_6 R$$

(2)

Where, $R = \sqrt{R_{epi}^2 + C_7^2}$

Y : spectral acceleration or peak ground acceleration

M : Moment magnitude, $M = 2.715 - 0.277\,M_L + 0.127M_L^2$

R_{epi} : epicentral distance

R : hypocentral distance

Table 2. Input parameters for the attenuation equation

Freq.(Hz)	C1	C2	C3	C4	C5	C6	C7
0.5	-0.74	1.86	-0.31	0.92	0.46	0.0017	6.9
1.0	0.09	1.42	-0.20	0.90	0.49	0.0023	6.8
2.5	1.07	1.05	-0.10	0.93	0.56	0.0033	7.1
5.0	1.73	0.84	0.00	0.98	0.66	0.0042	7.5
10.	2.37	0.81	0.00	1.10	1.02	0.0040	8.3
25.0	3.68	0.80	0.00	1.46	1.77	0.0013	10.5
35.0	4.00	0.79	0.00	1.57	1.83	0.0008	11.1
PGA	2.20	0.81	0.00	1.27	1.16	0.0021	9.3

Through the PSHA, seismic hazard curves were evaluated as shown in Figure 2 and Table 3. As shown in Figure 2 and Table 3, seismic hazard curves present annual exceedance probability versus peak ground acceleration. Seismic hazard curves represented as mean hazard also 15, 50 and 85 percentile hazard for indication of uncertainty range. In this study, example spectral hazard curves are developed using the available results of probabilistic seismic hazard analysis for a Korean radioactive waste repository site. Using the spectral hazard curves, the uniform hazard curve is generated. The uniform hazard spectrum with a return period of 10^{-4} was used for the generation of evaluation response spectrum (Shin et al., 1998).

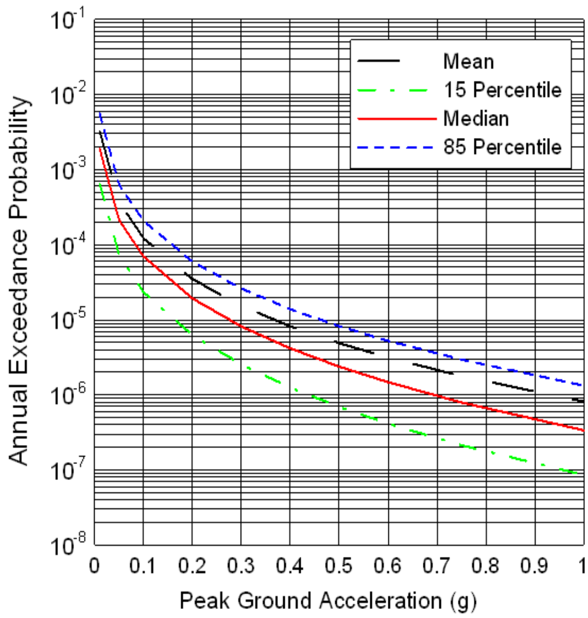
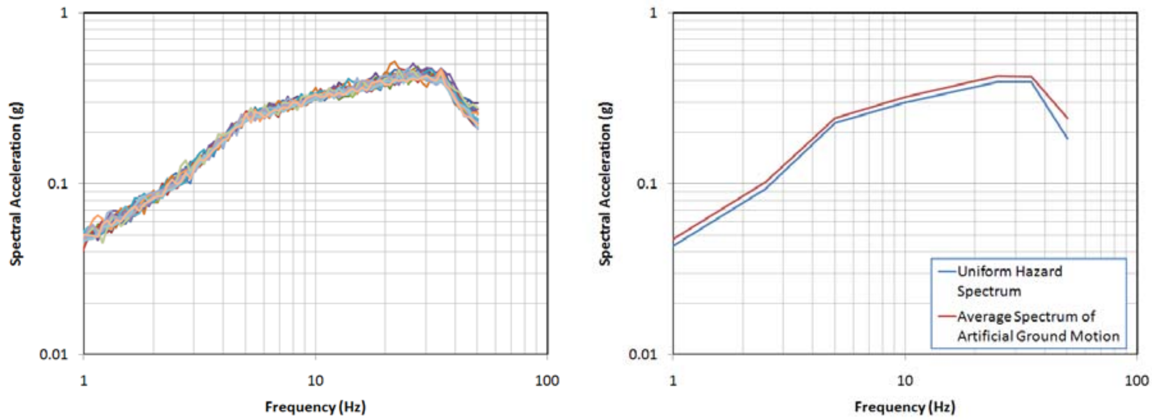


Fig. 2. Seismic hazard curves for radioactive waste repository site in Korea

Table 3. Annual exceedance probability of radioactive waste repository in Korea

PGA (g)	Average	15 Percentile	Median	85 Percentile
0.01	3.258E-03	6.520E-04	1.904E-03	5.558E-03
0.05	3.660E-03	7.153E-05	2.113E-04	6.242E-04
0.10	1.213E-04	2.321E-05	6.928E-05	2.068E-05
0.20	3.479E-05	6.237E-06	1.923E-05	5.926E-05
0.30	1.535E-05	2.542E-06	8.140E-06	2.607E-05
0.40	8.198E-06	1.253E-06	4.168E-06	1.387E-05
0.50	4.893E-06	6.931E-07	2.389E-06	8.235E-06
0.60	3.145E-06	4.151E-07	1.478E-06	5.263E-06
0.75	1.782E-06	2.139E-07	7.952E-07	2.956E-06
1.00	8.178E-08	8.591E-08	3.388E-07	1.336E-06

Artificial acceleration time histories which cover a uniform hazard spectrum were developed. For a development of artificial acceleration time history which satisfied uniform hazard spectrum, commercial computer program P-CARES which was developed in Brookhaven National Laboratory (BNL) was used (US NRC, 2007). Acceleration response spectrums of 30 artificial acceleration time histories are shown in Figure 3(a) and also comparisons between averages of 30 artificial acceleration time histories and target uniform hazard spectrums are shown in Figure 3(b). As shown in Figure 3, developed artificial acceleration time histories are well matched to target uniform hazard spectrum.



(a) (b)

Fig. 3. Artificial earthquake time history for uniform hazard spectrum; (a) acceleration response spectrum of 30 artificial earthquake time history (b) comparison between average acceleration response spectrum of 30 artificial acceleration time histories and uniform hazard spectrum

Site Response Analysis for Development of Evaluation Response Spectrum

For the development of an evaluation response spectrum, site response analysis performed for the target radioactive waste repository site in Korea. At first, target geologic sites were divided by soil, soft rock, rock and hard rock according to the boring data of target sites. A geological material property was determined by boring data and the results of experimental work and shear wave velocity of the ground were determined by elastic wave propagation test result. A seismic control point was decided as base rock and base rock was determined by shear wave velocity of 1500m/sec. The ground material property of the target radioactive waste repository site was summarized in Table 4.

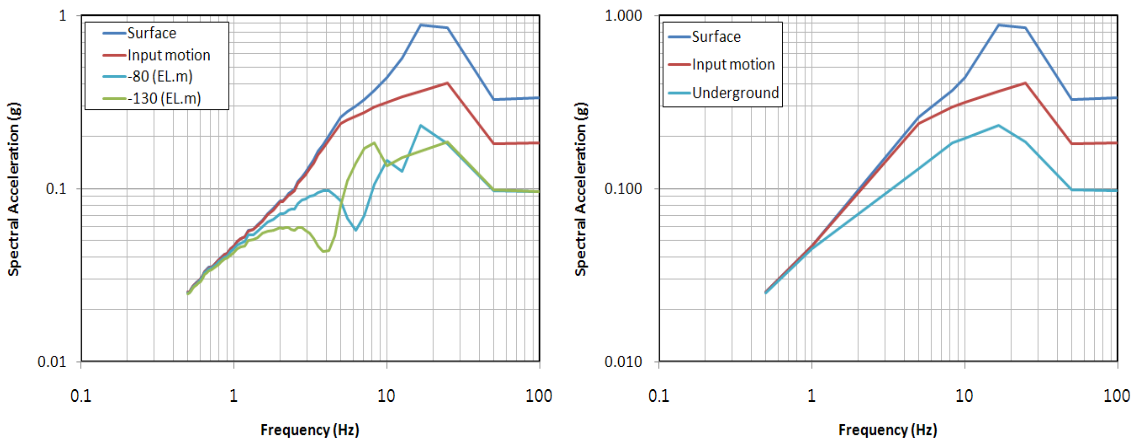
Table 4. Ground material property of target site

	Soil layer	Soft rock	Rock	Hard rock		
				0.5 (EL.m)	-80 (EL.m)	-130 (EL.m)
Density (g/cm^3)	1.65	1.90	2.70	2.90	2.90	2.90
Vs(m/s)	628.0	745	1500	2897	2580	3074
Layer thickness(m)	4.3	5.2	23.5	80.5	50.0	70.0
Poisson's ratio	0.33	0.3	0.27	0.20	0.23	0.12

For the performing a seismic response analysis, a well-known commercial computer program Pro-SHAKE was used (Schnabel et al., 1972). In the case of SHAKE analysis, basically frequency domain analysis was performed. In the case of frequency domain analysis, ground nonlinearity should be considered as equivalent linear method. In the case of the equivalent linear method, soil nonlinearity can be considered as iterative calculation of shear strain dependent shear modulus and damping ratio.

Development of Evaluation Response Spectrum

Seismic response analyses were performed using the SHAKE program for the 30 artificial earthquake time histories. Acceleration responses through the seismic response analyses are shown in Figure 4(a) according to depth. As shown in Figure 8, acceleration response at the surface is not much amplified before 5 Hz, but a little amplified after the 5 Hz region. A zero period acceleration is almost twice amplified compare to an input acceleration time history. A top and bottom positions of the cavern located at -80m and -130m level, respectively, acceleration response spectra are little different according to a frequency range. The differences in acceleration responses almost disappeared after 20Hz region. As to the reason why the acceleration responses are little different before 20Hz region, it may be that the shear wave velocity of hard rock location is a little different according to the depth as shown in Table 4. A relatively soft region is located between -80 to -130m depth. The zero period acceleration were decreased as 0.097g. Finally, an evaluation response spectrum for underground cavern system in low and intermediate level radioactive waste repository was proposed in Figure 4(b) and Table 5.



(a) (b)

Fig. 4. Acceleration response spectrum according to a depth of the radioactive waste repository system in Korea, (a) Numerical results of seismic response analysis, (b) An evaluation response spectrum for seismic risk assessment for low and intermediate level radioactive waste repository system

Table 5. An evaluation response spectrum for seismic risk assessment for low and intermediate level radioactive waste repository system

Frequency (Hz)	Surface	Input motion	Underground
100	0.334	0.184	0.097
50	0.328	0.182	0.099
25	0.844	0.408	0.187
16.67	0.877	0.365	0.231
10	0.439	0.315	0.195
8.33	0.367	0.296	0.184
5	0.258	0.237	0.130
1	0.047	0.047	0.045
0.5	0.025	0.025	0.025

RESULTS AND CONCLUSION

A seismic risk assessment for low and intermediate level radioactive waste repository is developing in this study. This paper deals with only 1st year results among the whole three year research project. Especially, in this study, development of an evaluation response spectrum for the seismic risk analysis about underground storage system was focused. For the development of the evaluation response spectrum, a seismic hazard analysis, an evaluation of uniform hazard spectrum, a generation of artificial time history acceleration and a site response analysis were performed. Through this study, an evaluation response spectrum for seismic risk assessment of radioactive waste repository was proposed. The maximum acceleration of developed evaluation response spectrum for an underground cavern system decreased by 53% compared to input bedrock seismic motion.

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