A Feasibility Study on the Inspection System Development of Underground Cavities Using Neutron Source

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1. Introduction

In these days, as underground cavities, lots of ground failure accidents have been noted in Korea. Especially, if the sinkhole accidents occur in urban region, it can lead heavy casualties. To protect the citizens from the sinkhole hazard, they should be detected using some specific inspection method. It is noted that gravimetry, magnetometry, and ground-penetrating radar (GPR) methods [1] are the representative searching methods of sinkholes. The gravimetry is the method to search the cavities by detecting the differences on the acceleration of the gravity. The detection efficiency using the gravimetry method is significantly low; therefore, it requires large surveying time. The magnetometry method detects the cavities by the magnitude of the magnetic field. However, the magnetometry method is problematical in urban areas due to pipes and electrical installations [1]. GPR is the method that uses high-frequency electromagnetic wave. This method is widely used for the inspection; however, the detection accuracy of sinkholes can be low in specific soil types [2]. To overcome the limitations of the present inspection system, in this study, a feasibility of a neutron source based inspection system is studied to detect cavities.

2. Methods and Results

2.1 Detection Capability Test

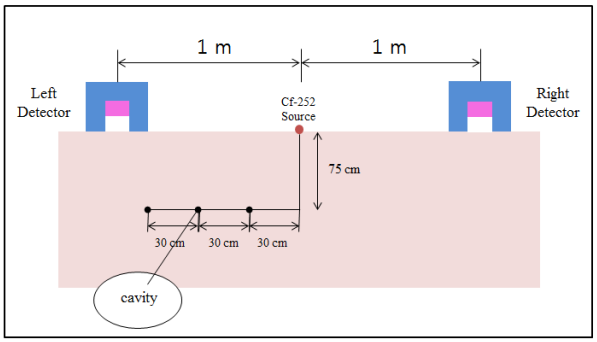

Fig. 1. Overview of the Detection System for the Feasibility Study

In order to validate the possibility of the sinkhole detection using neutron source, a detection simulation was set. The overview of the simulation system is shown in Fig. 1. A point neutron source is located at the center and left and right neutron detectors are located at 1 m apart from the source. It is assumed that the cavity is located near the left detector to observe the difference of two detectors. For the feasibility of the cavity detection, it is assumed that the neutrons having a Cf-252 source energy distribution are toward to bottom direction. The spectrum of the Cf-252 source [3] is given as shown in Fig. 2. To study how the geometrical features of the cavities affect the detection results, the simulation is carried out by changing the positions, sizes and shapes of cavities. The center position of the sinkhole is fixed to 75 cm depth, and the radial positions are decided at x = -30 cm, -60 cm and -90 cm (left direction). The shapes of the cavity are sphere and cubic. And, the sizes of them are selected to 50 cm and 100 cm of diameter for the sphere and length for the cubic, respectively. The material compositions of the land are chosen to the general dry soil covered by 5 cm of asphalt for describing the urban roadway [4].

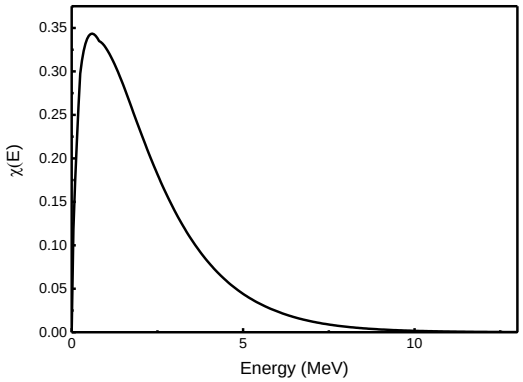

Fig. 2. Neutron Energy Spectrum of Cf-252 Source

Table I: Estimation Conditions for the Sensitivity Study on Detecting the Sinkholes

Case	Material Composition	Cavity Shape	Cavity Position [cm]	Cavity Size
#0	Dry Soil + 5 cm Asphalt	No cavity		
#1		Sphere	30	D = 50 cm
#2				D = 100 cm
#3			60	D = 50 cm
#4				D = 100 cm
#5			90	D = 50 cm
#6				D = 100 cm
#7		Cubic	30	L = 50 cm
#8				L = 100 cm
#9			60	L = 50 cm

#10				L = 100 cm
#11			90	L = 50 cm
#12				L = 100 cm

* D is diameter of sphere, and L is the unit length of the cubic.

2.2 Result and Analysis

The simulation was pursued by MCNPX 2.7 Code [5]. The calculated result is compared by the ratio of the left and right detector to observe the differences of the detector responses. It is assumed that the subsurface characteristics are not changed in a short distance. Table II shows the results of the simulations for a neutron source according to change of the geometrical features. Also, Fig. 3 shows the detection fraction (detection rate for the cavity case per the case without cavity).

Table II: Calculation Results According to Change of Geometrical Features

Case	Detector Location				Ratio (Left/Right)
	Left		Right		
	Intensity [#/cm^2]	Relative Error	Intensity [#/cm^2]	Relative Error	
#0	4.78E-08	0.0155	4.87E-08	0.0154	98 %
#1	4.97E-08	0.0076	4.81E-08	0.0078	103 %
#2	7.46E-08	0.0064	4.14E-08	0.0084	180 %
#3	4.99E-08	0.0076	4.85E-08	0.0077	103 %
#4	8.30E-08	0.0061	4.73E-08	0.0078	176 %
#5	4.87E-08	0.0077	4.86E-08	0.0077	100 %
#6	5.96E-08	0.0071	4.84E-08	0.0077	123 %
#7	5.16E-08	0.0075	4.73E-08	0.0078	109 %
#8	1.04E-07	0.0055	3.68E-08	0.0089	282 %
#9	5.24E-08	0.0075	4.84E-08	0.0077	108 %
#10	1.32E-07	0.0049	4.41E-08	0.0081	299 %
#11	4.94E-08	0.0077	4.86E-08	0.0077	102 %
#12	7.38E-08	0.0064	4.82E-08	0.0077	153 %

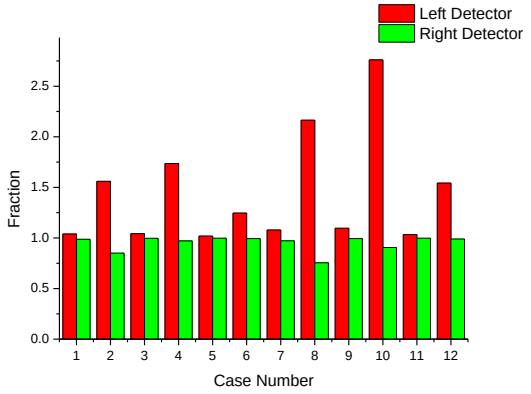

Fig. 3. Detection Fraction Based on the Detector Response of the Non-Cavity Cases

The results of the even number of the cases in Table II indicate that the differences between left and right detectors are considerably changed, while the differences are small for those of the odd number cases. Analysis shows that the sinkhole can be detected by using neutron when the cavity size is over ~ 100 cm. Also, as the radial location of the cavity is away from the source, detection efficiency is lower as shown in case #5, #6, #11 and #12. Fig. 3 shows the fraction of the left and right detectors per those of non-cavity case. The right detector responses are almost equal with non-cavity case, and the left detector responses have higher values. Also, they have a peak at the x=-60. In case #2 and #8, the fraction of the right detector is slightly low, it is because the cavity is overlapped at the centerline of the source. All analysis results show that it has a possibility to detect the sinkholes with proper conditions.

3. Conclusions

In this study, to verify the feasibility of the neutron source-based inspection system to detect the cavity detection, the Monte Carlo simulation was performed using neutron source. The analysis shows that the detection of the cavity with the given condition is possible when the diameter of cavity is over 100 cm. However, the detection efficiency can be enough increased if some optimization strategies for the inspection are developed. Also, it is expected that the proposed inspection method can detect the expected locations of the cavities. The inspection method will contribute the development of high performance inspection system for the cavity detections after an additional research is pursued.

4. Acknowledgement

This work was supported by National Research Foundation of Korea (NRF, 2014M2A8A1029801) grant funded by the Korea government (MEST, 2012M2A2A6004263), and Innovative Technology Center for Radiation Safety (iTRS)

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