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Sensitivity Analysis of Evacuation Speed in Hypothetical NPP Accident by Earthquake

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1. Introduction

Effective emergency response in emergency situation of nuclear power plant (NPP) can make consequences be different therefore it is regarded important when establishing an emergency response plan and assessing the risk of hypothetical NPP accident.

Situation of emergency response can be totally changed when NPP accident caused by earthquake or tsunami is considered due to the failure of roads and buildings by the disaster. Many kinds of elements related to mitigating actions can be different in earthquake scenario such as:

- delay time of sheltering,
- delay time of evacuation,
- evacuation speed,
- proportion of evacuees who fail to evacuate,
- and etc.

In this study evacuation speed has been focused among above various factors and reasonable evacuation speed in earthquake scenario has been investigated. Finally, sensitivity analysis of evacuation speed in hypothetical NPP accident by earthquake has been performed in this study.

2. Methods and Results

Previously to the sensitivity analysis of evacuation speed, it is necessary to investigate and establish evacuation scenario supported by reasonable evacuation speed. Seismic evacuation model has been built after the investigation of the evacuation speed in earthquake situation. Applying the established evacuation model, sensitivity analysis of evacuation speed in hypothetical NPP accident by earthquake has been carried out by using MACCS code [1].

2.1 Investigation of Evacuation Speed in Earthquake Situation and Establishment of Earthquake Evacuation Model

Normal evacuation speed of the reference plant site has been estimated in the study on public evacuation time estimate (ETE) within emergency planning zone (EPZ) [2]. Evacuation is conducted by using vehicles in normal evacuation scenario and free velocity of vehicles on the road is presented in Table I. In the reference study, the speed of vehicles in adverse weather has been determined 50% of the speed of vehicles in normal weather condition conservatively.

Table I. Speed of Vehicle in Normal Evacuation Scenario [2]

	Daytime		Night	
	Normal weather	Adverse weather	Normal weather	Adverse weather
Free velocity on the road (mile/hr)	30	15	25	12.5

The evacuation speeds presented in Table I have been used as reference evacuation speed of normal evacuation scenario for the purpose of comparing to the earthquake evacuation scenario. The durations of early, middle and late phase evacuation period were determined as 30 minutes, 105 minutes, and the remainder of the evacuation duration respectively referred to the reference study [2]. An hour of offsite alarm delay time, 2 hours of sheltering delay time and 45 minutes of evacuation delay time were assumed in this study. Daytime free velocity of a vehicle in normal weather (30 miles/hour) was used for the early and late phase of the evacuation period and nighttime free velocity of a vehicle in adverse weather (12.5 miles/hour) was used for the middle phase of the evacuation period because worse traffic jam is expected during middle phase of the evacuation period when it is compared to the other periods.

Contrastively to the reference evacuation scenario, evacuation speed in earthquake situation should be investigated. The speeds of a vehicle in normal and adverse weather for the reference site have been already obtained from the reference study [2]. Walking speed of evacuees has been investigated for the earthquake evacuation scenario. Walking evacuation is expected after the failure of evacuation using a vehicle due to intense traffic jam, failure of buildings and roads, and etc. Walking evacuation speeds are introduced in Fig. 1 and Table II. Mean walking speed of unimpaired adult has been found to be 1.43 m/s [3].

Table II. Walking Travel Speed Statistics (m/s) for Each Travel Speed Group, Compiled from Travel speeds in the 15 Literatures [3]

	Adult impaired	Adult unimpaired	Child	Elderly	Running
No. of sources	6	20	3	11	3
Min	0.58	0.88	0.56	0.21	1.79
Max	1.07	2.80	2.10	1.30	3.83
Mean	0.87	1.43	1.29	0.90	2.77
S/D	0.18	0.50	0.78	0.30	1.02

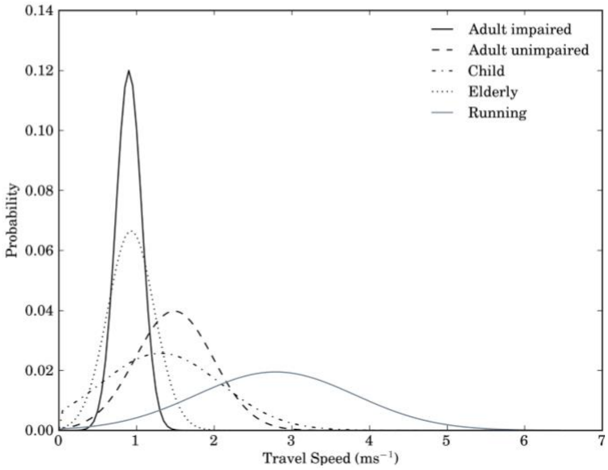

Fig. 1. Normal Distribution of Travel Speed for Each Evacuee Group Based on Statistics Presented in Table II [3]

Walking evacuation speed is also related with population density. Population density is increased due to panic conditions and social attachment phenomena, physical contact by facing bottleneck, and the tendency of pedestrians moving toward a larger group [4].

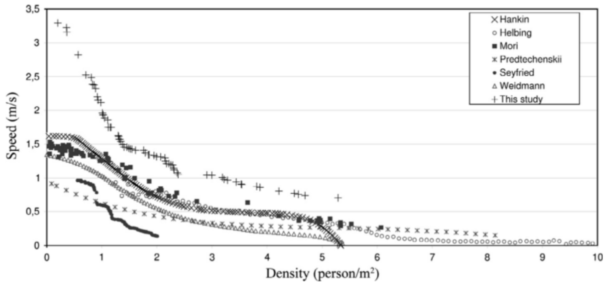

Fig. 2. Speed–density Relationships in References [4]

Reference study concluded that pedestrians prefer to move with 2.3-3 m/s of instantaneous speed [4]. Figure 3 shows instantaneous speed distribution of outdoor evacuation in earthquake situation [4].

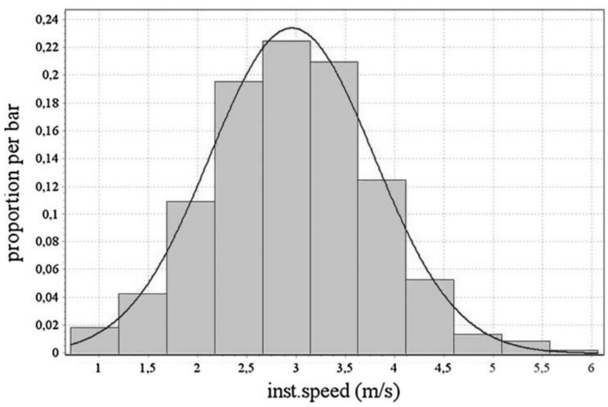

Fig. 3. Instantaneous Speed Distribution of Outdoor Evacuation in Earthquake Situation [4]

Another reference study is introducing about fear of building phenomenon which is describing the characteristics that evacuation speed becomes faster when pedestrians are closer to a building. Fear of building phenomenon is demonstrated in Figure 4 [5].

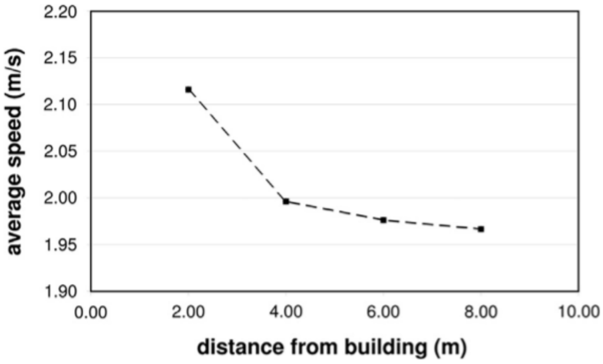

Fig. 4. Average Speeds of 15 Pedestrians According to Their Distance from a Building [5]

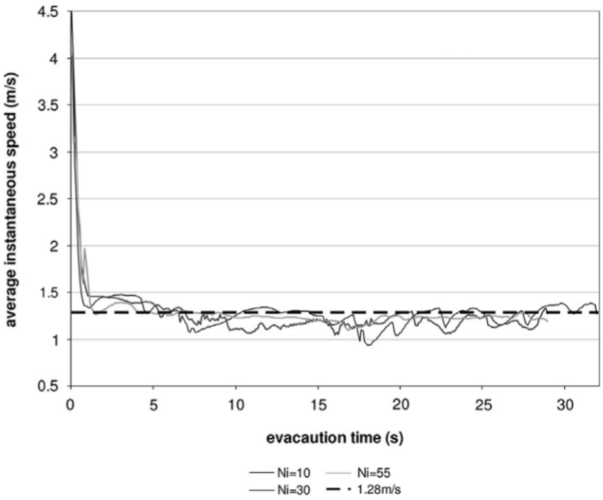

Fig. 5. Average Instantaneous Speed by Evacuation Time for Three Different Evacuation Groups [5]

Figure 5 is describing the average instantaneous speed by evacuation time and dashed line is the average speed for the three groups which is 1.46 m/s preferred speed of adult [5].

In accordance with the above references, travel speed of walking evacuee has been determined as 1.46 m/s for the sensitivity analysis. The earthquake evacuation model for the sensitivity analysis has been established including reference evacuation model and it is described in Table III.

Table III. Earthquake Evacuation Model for the Sensitivity Analysis (m/s)

	S1 (Ref.)	**S2**	**S3**	**S4**	**S5**
Early phase	13.40	5.59	5.59	5.59	1.46
Middle phase	5.59	5.59	5.59	1.46	1.46
Late phase	13.40	5.59	1.46	1.46	1.46

Five kinds of evacuation scenarios have been developed considering that evacuees may convert their evacuation method from using a vehicle to a walking when they face the difficulty of using a vehicle due to traffic jam of chaotic situation. Scenario 1 is the reference evacuation model in normal evacuation scenario. Scenario 2 consists of slow vehicle speed for whole period of evacuation. Evacuation situation is getting worse from scenario 2 to scenario 5 considering a seismic hazard situation. For example, scenario 5 considers walking evacuation during whole evacuation period.

2.2 Sensitivity Analysis of Evacuation Speed in Hypothetical NPP Accident by Earthquake

Consequence analysis has been conducted for each evacuation scenarios established in the earthquake evacuation model.

Three kinds of reference source terms considering the timing of source release such as early, intermediate, and late release were used for the sensitivity analysis. Summary of the each source term is presented in Table IV.

Table IV. Reference Source Terms Used in Sensitivity Analysis

	Early Release	**Intermediate Release**	**Late Release**
Reactor Type	Korean PWR with 1,000 MWe		
Source Term Category	STC-19	STC-04	STC-14
Initiating Event	LOOP	TLOCCW	TLOCCW
Major Events	NOTISO	ECF, LEAK	LCF, RUPTURE
Delay Time of Release	2.25 hours	19.25 hours	48 hours
Release Fractions after 72 Hours	- Xe: 100% - CsI: 31%	- Xe: 98.7% - CsI: 3.67%	- Xe: 100% - CsI: 0.994%

Meteorological data and population data of the reference NPP site were used and consequence analysis has been performed by using MACCS2 code [1]. 99.5% of population was assumed to follow evacuation model and 0.5% population was assumed to break the evacuation instruction and do normal activity referred to the reference [6]. 5 km and 30 km distance were considered for dose estimation regarding the maximum distances of precautionary action zone (PAZ) and urgent protective action planning zone (UPZ) of Korea. Source release amount during 72 hours was assumed to be released during the first one hour conservatively. Only the exposure of evacuees in emergency phase (one week) was regarded in this study.

Population dose within 5 km / 30 km normalized to the population dose of evacuation scenario 1 (reference evacuation scenario) have been calculated. In other words, population dose of reference evacuation scenario has been set as 1, and then population dose of the other scenarios were relatively compared to the population dose of reference evacuation scenario.

2.2.1 Early Source Release Scenario

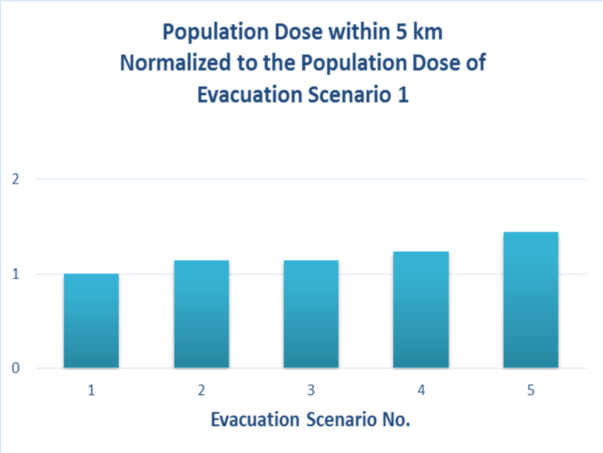

Fig. 6. Population Dose within 5 km Normalized to the Population Dose of Evacuation Scenario 1 (reference scenario) in Early Source Release Scenario

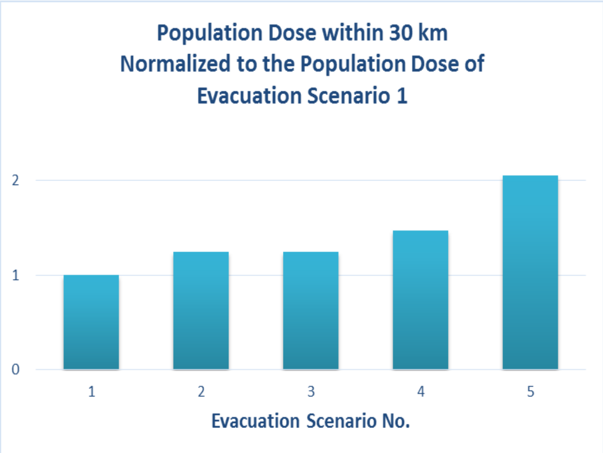

Fig. 7. Population Dose within 30 km Normalized to the Population Dose of Evacuation Scenario 1 (reference scenario) in Early Source Release Scenario

Fig. 6 and Fig. 7 describe the population dose within 5 km / 30 km normalized to the population dose of reverence evacuation scenario in early source release scenario. Population dose have been found to increase in earthquake evacuation scenario and 1.5 ~ 2 times higher in the whole-period walking evacuation scenario compared to the reference evacuation scenario.

2.2.2 Intermediate and Late Source Release Scenario

Evacuees have evacuated before plume arrival therefore dose has not appeared in the intermediate and late source release scenario, if 100% evacuees are assumed to follow evacuation scenario. Dose appears in only 0.5% of the population who do not follow the evacuation instruction but conduct normal activity. Population dose led from 0.5% population is relatively very lower than population dose estimated in early source release scenario.

3. Conclusions

Evacuation scenario can be entirely different in the situation of seismic hazard and the sensitivity analysis of evacuation speed in hypothetical NPP accident by earthquake has been performed in this study. Various references were investigated and earthquake evacuation model has been developed considering that evacuees may convert their evacuation method from using a vehicle to walking when they face the difficulty of using a vehicle due to intense traffic jam, failure of buildings and roads, and etc.

The population dose within 5 km / 30 km have been found to be increased in earthquake situation due to decreased evacuation speed and become 1.5 ~ 2 times in the severest earthquake evacuation scenario set up in this study.

It is not agreed that using same emergency response model which is used for normal evacuation situations when performing level 3 probabilistic safety assessment for earthquake and tsunami event. Investigation of data and sensitivity analysis for constructing differentiated emergency response model in the event of seismic hazard has been carried out in this study. Furthermore, the method and trial suggested in this study are expected to be used for the development of differentiated emergency response model regarding the earthquake and tsunami in further studies.

4. Limitations of the Study

Only three kinds of source release scenarios have been considered in this study such as early, intermediate, and late source release scenario representatively. Therefore, intermediate level between each scenario could not be taken into account in this study. More various kinds of scenario with regard to source release characteristics should be considered in further studies.

It seems that earlier evacuation speed is more important than later evacuation speed in the evacuation period when the trend of the result is analyzed. But this could be derived from the assumption that source release amount during 72 hours are released in the first one hour conservatively. Further study with more realistic source release scenario rather than conservative scenario is necessary to investigate the importance of earlier evacuation speed compared to later evacuation speed.

Frequencies of each source term categories have not been considered in this study and it should be noted that only consequence analysis has performed in this study rather than risk assessment considering both consequence and frequency.

Acknowledgement

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