Assessment of Damage to Building and Human Casualty at Uljin-gun Bukmyeon Nuclear Power Plant Support Facility in the Event of a Seismic at Hanul Nuclear Power Plant (0.3g)

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1. Introduction

When a seismic, the nuclear power plant (NPP), the surrounding essential infrastructure, and emergency response facilities may suffer extensive damage. In such cases, emergency response activities for resident protection and accident management must be carried out by significant response agencies—such as local government offices, fire departments, police stations, and hospitals—and by support personnel from the NPP by procedures set by the Nuclear Safety Commission [1]. However, if these emergency response agencies (e.g., fire departments, public health centers, local government offices) are damaged, a prompt response during a nuclear accident may be hampered. Furthermore, damage to infrastructure such as power systems, transportation networks, and communication systems can delay the activation of support systems necessary for NPP operation and accident response.

This study evaluates building damage caused by seismic activity at a NPP site. It estimates human casualties on an individual building basis to assess the damage status of buildings and response agencies in the surrounding area. The study area is the Hanul NPP site, and the Safe Shutdown Earthquake (SSE) level of PGA 0.3g (for the Shin Hanul NPP located on this site) was used as the input parameter for the seismic attenuation equation. This equation computed spectral acceleration values corresponding to specific structural periods for each building location. Subsequently, seismic fragility functions explicitly developed for various structural types of Korean buildings were applied to determine building damage ratios [2]. The number of human casualties, including fatalities and displaced individuals, was estimated based on the calculated building damage ratios.

2. Seismic Damage Assessment Method

2.1 Building Damage Assessment Method

The assessment was based on the structural damage assessment methods presented by the Ministry of the Interior and Safety(MOIS) reports and Eem et al., requiring information on building characteristics, fragility functions by structural type, and seismic spectral acceleration (SA(g)) [2, 4]. Information such as structural type, construction date, and spatial data were obtained from Opendata. The seismic fragility curves developed in the MOIS report were used [2]. This report provides fragility information for 42 architectural and structural types with four damage states (Slight, moderate, extensive, and complete) and details by seismic design level [2]. The seismic spectral acceleration (Sa(g)) was calculated using the attenuation equation proposed by Jo et al. [3]. By combining the SA(g) values at each building location with the fragility curves for the respective structural types, the exceedance probability for each damage state was derived. The building damage ratio can then be calculated using the exceedance probabilities for each damage state—obtained via equation (1)—and the expected loss ratios for each damage state—shown in equation (2). The expected loss ratios for each damage state are listed in Table I [4].

$$\begin{gathered} P[ds = No\ damage] = 1 - P[ds > Slight] \\ P[ds = Slight] = P[ds > Slight] - P[ds > Moderate] \\ P[ds = Moderate] = P[ds > Moderate] - P[ds > Extensive] \\ P[ds = Extensive] = P[ds > Extensive] - P[ds > Complete] \\ P[ds = Complete] = P[ds > Complete] \end{gathered} \quad (1)$$

$$\mu_d = \Sigma_{i=1}^{4}[P[ds_i|S_a] \cdot \mu_{D|dsi_i} \quad (2)$$

Where, μ_d is damage ratio of building
$P[ds_i|Sa]$is exceedance probability for damage state
$\mu_{D|dsi_i}$is expected loss ratios for damage state

Table I: Expected loss ratio of each damage state [4]

Damage State	Expected loss ratio
Slight Damage	0.5
Moderate Damage	15.5
Extensive Damage	55
Complete Damage	90

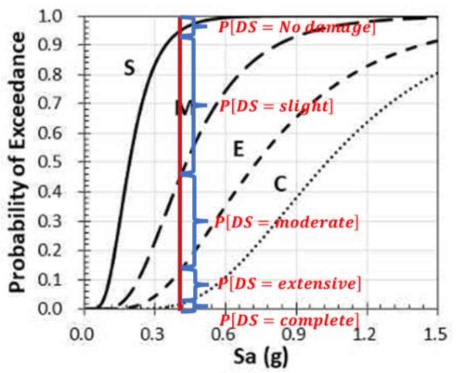

Fig. 1. Exceedance probability for each damage state.

2.2 Estimation Method for Human Casualties

The estimation method for human casualties followed the approach provided by the MOIS, which estimates fatalities and injuries (casualties) and the total number of displaced persons [2]. Using the building damage assessment results and information on the number of people staying in or residing in each building, casualties by level and the total number of displaced persons were calculated. The casualty levels were divided into four categories, as shown in Table II. While the MOIS report originally performed estimations by administrative district, in this study, the data were transformed for an evaluation on an individual building basis by setting damage state ranges according to the building damage ratio. The Ministry's estimation of displaced persons categorizes them into four types, considering not only the structural damage of buildings but also factors such as loss of utilities and psychological and social impacts. The total number of displaced persons was derived by summing the estimates for all categories.

Table II: Definition of casualty levels [2]

Casualty Level	Definition
Level 1	Injuries requiring basic medical treatment without hospitalization
Level 2	Injuries requiring significant medical treatment and hospitalization but not life-threatening
Level 3	Injuries potentially life-threatening if sufficient and prompt medical treatment is not provided
Level 4	Immediate fatality

3. Seismic Damage Assessment Results

The above methodology, the building and human casualty damages of the nuclear power plant support facilities in the Bukmyeon region of Uljin-gun were assessed using the SSE level of PGA 0.3g (Mw 6.32) for the Shin Hanul Nuclear Power Plant located on the Hanul NPP site. The building damage assessment was expressed as the "average damage ratio," the arithmetic mean of the damage ratios calculated for individual buildings grouped by facility type. Table III summarizes the building damage and human casualty assessment results for the NPP support facilities in Bukmyeon.

According to the building damage assessment results in the Bukmyeon region, local government offices exhibited the highest average damage ratio (48.19%), indicating damage at a half-collapsed level. Next, the fire station showed a high average damage ratio of 46.79%. The KHNP residences (housing for NPP support personnel), comprising 31 houses, had an average damage ratio of 30.16%, suggesting damage between light and half-collapsed levels. In contrast, the police station had a relatively low average damage ratio of 15.34% and is expected to suffer only minor damage at the light damage level.

In the human casualty assessment for the Bukmyeon region, the total number of displaced persons was estimated to be 380 at the KHNP residences. Since estimating displaced persons applies only to residential buildings, this assessment was performed solely for the KHNP residences. Furthermore, the number of casualties was highest at the KHNP residences, while other facilities were expected to have almost no level-1 casualties.

4. Conclusions

In this study, the building and human casualty damages for major nuclear power plant support facilities and residential facilities in the Bukmyeon region of Uljin-gun were evaluated using the SSE level of PGA 0.3g (Mw 6.32) for the Shin Hanul NPP located on the Hanul NPP site as the input parameter. The results indicate that in an earthquake, local government offices and fire stations would experience high average damage ratios of 48.19% and 46.79%, respectively—suggesting damage at a half-collapsed level. The KHNP residences comprising 31 houses showed an average damage ratio of 30.16%, indicating damage between light and half-collapsed levels. It was further analyzed that, as a consequence, up to 380 displaced persons and 408 casualties could occur. In contrast, the police station exhibited a relatively low average damage ratio of 15.34%. Although the damage estimates derived using the methods presented in this study may differ from actual conditions, they can be used to understand the overall damage trend. It is expected that the results of this study will help improve the understanding of facility and human casualty situations for more effective emergency response measures in the event of a nuclear accident.

Table III: Seismic damage assessment results in Uljin Bukmyeon

Response Agencies List	Total number of Buildings	Average Building Damage Probability (%)	Casualties by level 1	Casualties by level 2	Casualties by level 3	Casualties by level 4	total Victims	Maximum resident population per hour
Public medical institution	1	40.47	0	0	0	0	0	2
KHNP residences	31	30.16	408	75	13	13	380	2101
Fire station	1	46.79	1	0	0	0	0	4
Local government office	3	48.19	2	0	0	0	0	6
Local police station	1	15.34	1	0	0	0	0	16

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