Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Accident Sequence Analysis for Beyond Design Basis External Hazards

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***Keywords :** Probabilistic safety assessment, External hazard, High wind, External flooding, Accident sequence analysis

1. Introduction

Nuclear power plants (NPPs) in Korea are located along the coast and can be affected by natural hazards such as typhoons, heavy rains, and storm surges. The plants are designed to be safe against these external hazards, and the probabilistic safety assessment (PSA) also excludes them from target of the analysis due to their extremely low impact.

However, due to the phenomenon of climate change, the intensity of typhoons and amount of precipitation are expected to increase, and the safety of plants in external hazards that exceed design basis maybe uncertain.

Therefore, as a part of PSA for beyond design basis external hazards, this study investigates the effect of high wind and external flooding hazards, which are representative external hazards that can occur in Korea, on domestic NPPs and derives accident sequences that can occur in each hazard.

2. Methods and Results

2.1 PSA process for External Hazard

Basically, PSA for external hazard is performed through the following three elements: (1) Hazard analysis, (2) Fragility analysis, (3) Plant response model and quantification [1]. First, hazard analysis selects external hazards that can occur ate the target site and evaluates the frequency of occurrence of each hazard. High wind hazards include typhoons, tornadoes, tropical cyclones, etc. and are estimates by the annual frequency of exceedance of peak wind speed (3 sec. peak-gust at 10m above open terrain). External flooding hazards include local intense precipitation (LIP), storm surge, and tsunamis, etc. and are assessed by the annual frequency of exceedance of peak flood elevation (Max. 1-hr flood elevation) or probable maximum precipitation (Max. 1-hr rainfall rate).

In the fragility analysis, SSCs (Structures, Systems, and Components) that are vulnerable to external hazards are selected through review of plant design data and walk-down, and the failure probability of each SSC is evaluated by identify the impact of each hazard. The impact on the NPPs may vary depending on the type of external hazard. In case of high wind hazards, direct damage due to wind loads or damage caused by a wind-borne missile may occur. For external flooding hazards, damage may occur due to hydrodynamic loads or the operation of plant system may fail due to high humidity or inundation. As the result of the fragility analysis, the probability of damage by specific hazard intensity, such as wind speed or flood elevation can be estimated.

These failure events are added into the internal event PSA model for reflecting the impact of each external hazard and quantified along with the frequency of occurrence obtained from the hazard analysis to assess the plant safety due to external hazards.

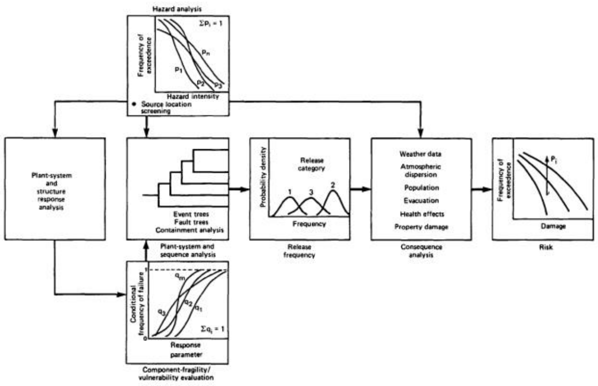

Fig. 1. Overview of External Hazard PSA [1]

In this study, SSCs that are expected to be vulnerable to high wind and external flooding hazards were selected and the effects on those SSCs for each hazard were reviewed to determine possible accident sequences.

2.2 High wind hazards

To analyze possible accident sequences for high wind hazards, it is necessary to understand the impact of these hazards on plants [2].

In high wind hazards, the wind loads delivered to a structure or equipment by high winds can exceed the design loads and cause direct damage. In addition, various structures or materials, such as tanks, pipes, etc. located within the plant or adjacent regions can act as wind-borne missile, striking exposed structures or equipment and causing damage.

To determine the accident sequences of high wind hazards, we investigated the failure events that could be caused by high winds by reviewing design data for the plant systems considered in the internal event PSA [3, 4].

Most of the structures located in the plants are reinforced concrete structures, which are not affected by high winds. However, the turbine building is a steel structure with exterior walls made of steel panels and can be affected by high winds more than other structures. Therefore, if the turbine building is damaged by high winds, it can also adversely affect the operation of main feed-water system located inside the building and, conservatively, may lead to loss of that system.

In addition, if the turbine building is damaged by high winds, steel panels that make up the exterior walls can act as wind-borne missile and affect nearby structures such as transformers, switchyards, transmission towers, and other equipment related to off-site power. If wind-borne missile approaches these structures, it can cause direct damage or instantaneous flashover, resulting in loss of off-site power.

Based on this, we can consider loss of main feed-water (LOFW) and loss of off-site power (LOOP) as the accident sequences of high wind hazards, and the causes of each sequences are summarized in Table I.

Table I: Causes of accident sequences of high wind hazards

Accident sequence	Related structures or equipment	Possible cause
LOFW	Turbine building	- Damage to main feed-water pumps or related piping due to high winds (impact on turbine building)
LOOP	Switchyards, transmission towers, etc.	- Collapse of transmission towers - Damage to switchyards caused by wind-borne missile

2.3 External flooding hazards

To analyze possible accident sequences for external flooding hazards, it is necessary to understand the impact of these hazards on plants [2].

External flooding hazards include LIP, storm surges, dam failure, and tsunamis, where LIP is defined as an extreme rainfall event with probable maximum precipitation for 1-hour over 1-square mile.

In terms of the impact on the plant during an external flooding event, if the water flooding into the plant accumulates above the operational flood level, structures and equipment may become flooded or operating condition such as humidity may change adversely, causing failure of operation.

In addition, in the case of a storm surge or tsunami, waves with wavelengths greater than the inundation barrier may enter the plant and directly strike structures and equipment. And material floating in the ocean can be washed into the plant by waves, causing damage such as blockage of intake or drain.

As mentioned above, the impact on the plant varies depending on the type of external flooding hazards. Therefore, we analyzed possible accident sequences for LIP as a representative external flooding hazard.

In the design stage of NPPs, design basis flood level is set to ensure the safety of the site against the probable maximum precipitation within the site and the ground floor elevation of safety-related structures is set above this flood level to prevent floodwater from entering into the building.

Therefore, in order to cause damage to the plant due to external flooding hazards, the flood level must reach above the ground floor elevation of the building from the site elevation, and flood protection features such as flood barriers, doors, and drainage facilities should be failed.

All safety-related structures are constructed with reinforced concrete walls above the design basis flood level, and the entrances to the outside are also located above that level. Even though the water level reaches above this level due to a LIP, the flood protection features will protect the equipment inside the structure, so the impact of flooding may be minimal.

The turbine building is a non-safety-related structure and is subject to external flooding hazards because it is a steel structure and the exterior walls are made of steel panels. And, an emergency drainage with louver of 138’(W)×4’(H) size is installed on the ground floor of this building against internal flooding such as pipe rupture, which can be considered as an inflow path from LIP. Therefore, flooding inside the turbine building could affect the operation of main feed-water system located inside the building.

In addition, because the turbine building is adjacent to the auxiliary building, it is possible to flood the auxiliary building through the interior of the building. However, the wall between the turbine building and the auxiliary building is designed as a flood barrier to prevent propagation of flooding.

Since the circulating water intake structure where the circulating water pump is located is also a non-safety-related structure, it may be vulnerable to flooding. Therefore, if the circulating water system cannot be operated due to flooding inside the structure, this may cause a loss of condenser vacuum.

Switchyard or transmission and distribution facilities that are located outdoors may not have flood protection and can be unavailable due to flooding.

Based on this, we can consider LOFW and LOOP and loss of condenser vacuum (LOCV) as the accident sequences of external flooding hazards, and the causes of each sequences are summarized in Table II.

Table II: Causes of accident sequences of external flooding hazards

Accident sequence	Related structures or equipment	Possible cause
LOFW	Turbine building	- Main feed-water pump inoperable due to flooding inside the turbine building
LOOP	Switchyards, transmission and distribution facilities, etc.	- Loss of off-site power due to flooding of switchyard or other off-site power related facilities
LOCV	Circulating water intake structure	- Circulating water pump inoperable due to flooding inside the circulating water intake structure

3. Conclusions

In this study, SSCs that are expected to be vulnerable to high wind and external flooding hazards were selected and the effects on those SSCs for each hazard were reviewed to determine possible accident sequences.

In high wind hazards, not only direct damage from high winds, but also damage from wind-borne missile can occur. Therefore, through review of design data for the plant systems considered in the internal event PSA, it was expected that turbine building and off-site power related structures located outdoors would be vulnerable to high wind hazards, and accordingly, LOFW and LOOP were considered as accident sequences of high wind hazards with conservative assumptions.

In the case of an external flooding hazards, possible accident sequences of the LIP were analyzed. In the LIP, if the water flooding into the plant accumulates above the operational flood level, structures and equipment may become flooded or operating condition such as humidity may change adversely, causing failure of operation. Therefore, in order to cause damage to the plant due to external flooding hazards, the flood level must reach above the ground floor elevation of the building from the site elevation, and flood protection features such as flood barriers, doors, and drainage facilities should be failed. By reviewing plant design data, it was expected that non-safety-related structures, such as turbine building, circulating water intake structure, and switchyard, would be vulnerable to flooding, and accordingly, LOFW, LOOP, and LOCV were considered as accident sequences of external flooding hazards with conservative assumptions.

Accident sequences of each external hazard derived from this study will be used as a basis for developing a PSA model for high wind and external flooding hazards, and in the future, we will conduct hazard analysis and fragility analysis for vulnerable SSCs to evaluate the plant safety due to high wind and external flooding hazards, and will confirm the effects of various climate change phenomena, using the PSA model to be developed.

ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean government (Ministry of Science and ICT) (No. RS-2022-00154571).

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