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The Study of Influence Factors on Flight Behavior of Wind-borne Debris

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1. Introduction

2~3 typhoons land on the Korea peninsula every year. These typhoons cause enormous both economic loss and personal injury damages.

Typhoon damage to structure, system and component (SSCs) can occur as a result of two types forces such as wind-induced forces and force induced by wind-borne debris impact.

The structure of nuclear power plants of Korea were governed by the earthquake load than wind load. These structures have an enough safety against wind load. But the impact of wind-borne debris can cause significant damage to the off-site component (power transmission tower, transformer, condensate storage tank) and structure with louver window.

In this study, the influence factors on traveling velocity of wind-borne debris was found from the previous research results

2. Damage by Wind-born Debris

Most typhoons are accompanied by turbulent winds that generate wind-borne debris. Typhoons are capable of generating debris from objects lying within the path of wind and from the debris of nearby damaged structures.

Hurricane Allen 1980 in Texas, USA, caused glass failures. It was discovered upon that the failures were caused by both debris impact and wind pressure [1].

Damage of SSCs by wind-borne debris under the influence of the typhoon leads to economic loss. It was observed that the source of wind-borne debris was cladding, construction material, pole and pipe. When the debris attack a power transmission tower or transformer the loss of off-site power can occur. In the case of a transformer, the functional failure may be occurred even if debris reaches it. And damage of CST by debris lead to loss of aux feed water.

3. Influence Factors on Flight of Wind-borne Debris

3.1 Potential of wind-borne debris

Potential projectiles includes roofing materials, inadequately attached cladding components and rocks and tree limbs [2]. According to the FEMA-361 [3], the literature on tornadoes and hurricanes contains numerous examples of large structural members that have been transported by winds for significant distances.

US NRC presented the regulatory guide to support reviews of applications that the agency expects to new NPPs constriction permits. According to the guidance, three wind-borne debris (e.g. Automobile, pipe and sphere) selected as shown table 1.

Table I : Design-Basis Debris Spectrum (NRC Reg.-1.221)

Type	Dimensions	Mass
Automobile	5m x 2m x 1.3m	1810kg
Schedule 40 Pipe	0.168m (D) x 4.58 m (L)	130kg
Solid Steel Sphere	25.4 mm (D)	0.0669kg

3.2 Equation of motion

The equations of horizontal and vertical motion of a missile in a flow with constant velocity vh are to be equation (1) and (2).

$$\frac{dv_{mh}}{dt} = (v_h - v_{mh})\left\{a[(v_h - v_{mh})^2 + v_{mh}{}^2]^{1/2}\right\} \quad (1)$$

$$\frac{dv_{mv}}{dt} = g + \frac{-amv_{mv}[(\mathrm{v}-v_{mv})^2+v_{mv}{}^2]^{1/2}}{m} \quad (2)$$

Where v_h is the horizontal wind speed at the variable elevation of the missile at time t, v_{mh} and v_{mv} are the horizontal and vertical missile speed at time t, respectively, g is standard acceleration of gravity.

Flight force and acceleration of wind-borne debris was defined by equation (3). From the eq. (1), the motion of wind-borne debris is affected by CdA/m. The Cd is closely related to the shape of debris. According to the test results of the Lin (2004), the mean and standard deviation of drag coeffcient can be defined as shown in table 2.

$$\mathrm{F} = 0.5\rho V_r^2 C_D A,\ a = 0.5\rho\left(\frac{C_D A}{m}\right) \quad (3)$$

Where the Cd, A and m are drag force, the area and mass of debris, respectively.

3.3 Factors on flight of wind-borne debris

The wind field model is an important parameter to define the motion of wind-borne debris. Holland model and Georgiou model was typically used to construct the wind field model.

Lin et. al.[5] performed the wind tunnel test to evaluate the displacement of debris under various conditions. From the test results, we found that the horizontal and vertical displacement of debris depended on type, aspect ratio, mass, initial boundary condition and angle of debris.

The relationship between the velocity of debris and the horizontal displacement of an object with an area of 0.09 m^2 and a mass of about 3 kg can be calculated using Equation (2). From the figure 1, it was presented that the plate flew farthest in the same wind speed.

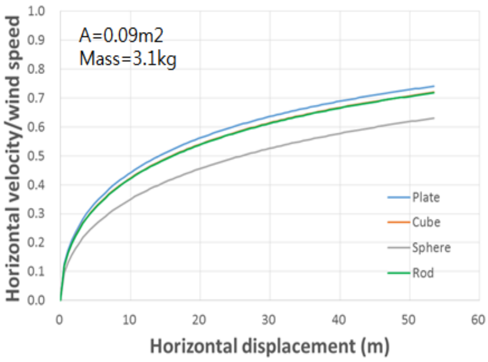

Fig. 1. Horizontal displacement of debris (type of debris).

The damage of target structure and component is greatly influenced by the velocity of wind-borne debris. Therefore, it is needed to analyze the influence factors on velocity of debris.

Table II : Drag coefficient by debris type

Type	Mean	Standard deviation
Plate	0.911	0.0814
Cube	0.809	0.0203
Sphere	0.496	0.0087
Pipe	0.801	0.0616

Will et. Al. [6] developed the flight velocity equation by debris type. The flight velocity was defined by the shape of debris, density of debris, air density, and drag force. The drag force depends on the type of debris as shown in table 2. The drag force of sphere has the largest value and that of plate has the smallest value. In other word, the sphere can move easily by the wind rather than other type of debris.

The velocity of debris can be calculated by using the equation (4). C is drag force and K is Tachikawa parameter which is the non-dimensional ratio of aerodynamic force to gravity forces. $\bar{u}$ is the ratio of wind speed (U) and velocity of debris (u_m). $\bar{x}$ is the displacement of debris by wind. Tachikawa parameter is defined by the characteristic of debris (area and mass) as shown in equation 5.

$$\bar{u} = 1 - e^{-\sqrt{2CK}} \quad (4)$$

$$K = \frac{\rho_a U^2 A}{2mg} = \frac{\rho_a U^2}{2hg\rho_m} \quad (5)$$

5. Conclusions

To perform high wind risk assessment of NPPs, we searched the influence factors on flight of wind-borne debris. Tachikawa parameter K greatly affected trajectories in the vertical and horizontal direction. Side ration and initial boundary condition affected trajectories in vertical direction.

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