Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

A Study on External Fire Damage of Structures subjected to Aircraft Impact

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1. Introduction

Aircraft impact assessment and protective design have been applied to most infrastructures as nuclear power plants, skyscraper etc. around the world. Basically, the assessment is carried out by using a realistic analysis method which is to evaluate the shock damages to target structures and internal and external fire damage to equipment due to jet fuel fire. The fire after aircraft impact is distinguished as external and internal fires.

A large commercial aircraft consists of various components as fuselage, wings, fuel tank, engine etc. During a collision of the aircraft, the fuel tank with a large amount of jet fuel have a significant effect on the total load of the aircraft as well as causing explosive fire and smoke which affect the safety of the structure and equipment.

US Sandia National Laboratories [1] and Finland VTT [2] etc. performed the test and simulation studies to evaluate the dispersion range of the fluid after the crash of liquid filled cylinder missiles. The test condition and results have been referred in this paper. As shown in Fig. 1, the fluid modeling approach using SPH is applied to evaluate the dispersing range of the fluid, and is compared with the Brown's results [1].

(a) Brown's Test Results (b)Analysis Results

Fig. 1. Compare the Brown's and analysis results

The jet fuel is idealized as particles contained in an aluminum cylinder missile, where those particles can be dispersed to the surrounding area after the missile crashes into a rigid target. The fluid model using the SPH method is briefly verified through comparison with test results, and then the modelling method is applied to a jet fuel model in an aircraft model. The dispersion analysis of jet fuel caused by aircraft impact is performed using an aircraft model for the determination of fire duration and fire affected zone in a nuclear power plant. Finally, the structural integrity of the roof of the structure during a jet fuel fire is evaluated.

2. Jet fuel Included Aircraft FE Model

The aircraft model is developed by referring to EPRI report [3] as shown in Fig. 2. Aircraft fuselage, wings, jet fuel storage tank, and engines are modeled with shell elements. The jet fuel in storage tank is modeled using SPH particles (Fig. 2) which are previously validated, and overall weight of the aircraft except jet fuel is appropriately distributed to the nodes with reference to the mass distribution along the aircraft axis.

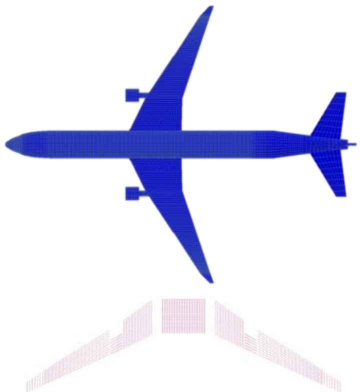

Fig. 2. Aircraft and Jet Fuel Model

The material properties of jet fuel are shown in Table 1. The Gruneisen equation of state correlated the material volumetric strength and pressure to density ratio as [4, 5]

$$P_H = \frac{\rho_0 C^2 \cdot \mu(\mu+1)}{\left[1-(s-1)\mu\right]^2}$$

Where

$$\mu = \frac{\rho}{\rho_0} - 1$$

Where ρ and ρ_0 are the initial and instantaneous densities of material, C is the intercept, and s is linear Hugoniot slop of shock velocity (v_s) and particle velocity (v_p) relationship.

It like hydrodynamic response by using Gruneisen EOS with negligible strength effects was implemented to liquid model. Thus, the liquid behaves as a fluid on the target wall and base.

Table 1.Jet Fuel Properties

Null Model for Liquid	
Density (kg/m^3)	1000
Pressure Cutoff	-1
Viscosity Coefficient	100
EOS_Gruneisen Constants for Liquid	
C	1483
S1	1.75
Gamma	1.1

3. External Fire Damage Analysis after Aircraft Impacts

When the aircraft impacts to nuclear power plant containment, jet fuel is diffused to the auxiliary building (AB) roof area and the subsequent fire may occur on the roof. Because structural integrity of the auxiliary building roof may be affected by the jet fuel fire, dispersion range of jet fuel to the roof area after aircraft crash is evaluated using aircraft model in this study. Jet fuel dispersion according to time is shown in Fig. 3.

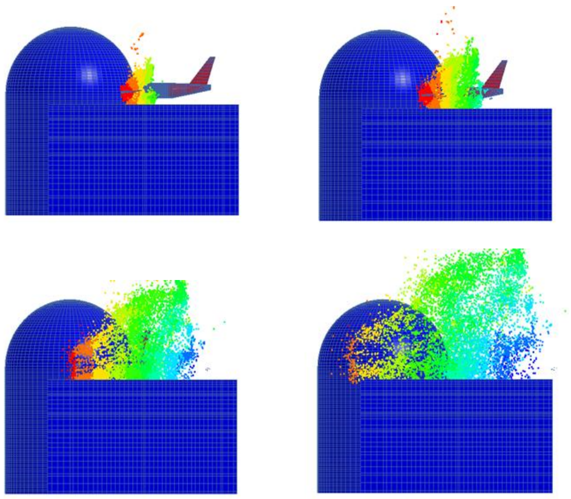

Fig. 3. Jet fuel dispersion according to time

A heat transfer analysis model for the auxiliary building which consists of reinforced concrete structure is shown in Fig. 4.

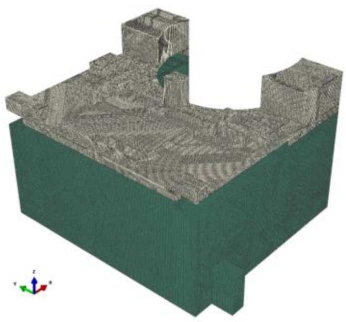

Fig. 4. Analytical models for auxiliary building

A heat transfer analysis considering the heat profiles on the roof outside surface of AB and inside constant operating temperature is performed first, and then a heat stress analysis considering the heat profiles in roof thickness and vertical loads is carried out using a nonlinear analysis method of ABAQUS [6]. All thermal properties of the material are followed the requirements of Euro codes.

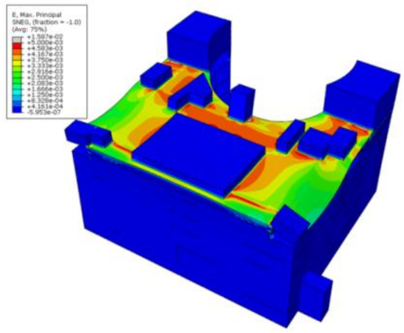

Fig. 5. Tensile strain contour on AB roof

The result of tensile strain contour for AB roof is shown in Fig. 5. The tensile micro-cracks of concrete are shown in the structure. The plastic strain state of top reinforcement on roof exceeds a yield strain. However, bottom reinforcement is in an elastic strain state. As results, although tensile cracks occur in concrete and top reinforcement, collapse of the roof does not expect to occur.

4. Summary

In this study, the filled jet fuel was modeled by using smooth particle hydrodynamics technique; jet fuel spread area following an aircraft crash was analyzed. Also, a heat transfer analysis for AB is performed based on the result of the dispersed jet fuel on the roof. As results, when nuclear power plant subjected to aircraft crash, collapse or destruction of the roof by fire does not occur although overall micro-cracks occur in roof.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2012M2A8A4009710)

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