Preliminary Study on Effect of Aviation Fuel in the Safety Evaluation of Nuclear Power Plant Crashed by Aircraft

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1. Introduction

As the safety assessments of nuclear power plants for the hypothetical large civil aircraft crash should be made mandatory, studies on large aircraft-nuclear power plant impact analyses and assessments are actively in progress. The large civil aircrafts are being operated with a large amount of fuel and the fuel can be assumed to contribute to the impact loads at the impact. The fuel, i.e., the internal liquid can be considered as added masses classically in the evaluation of the impact load. According to the recent experimental research, it has been shown that the impact load of high speed impacting body with internal liquid is much higher than that of the mass-equivalent impacting body. In this study, the impact loads according to the existence of the internal liquid are computed by numerical methods and the safety assessment of nuclear power plant crashed by large civil aircraft are performed as an application.

2. Impact load of body with internal liquid

Tests related to the safety assessment of reinforced concrete wall impacted by body with internal liquid have been performed by VTT[1] (Technical Research Centre of Finland). The experimental specimens of VTT impact tests are roughly 2 types shown in Fig.1. One is 1.5 m long; weighs approximately 50 kg. The other is 0.6 m long; weighs approximately 50 kg with 28 kg internal liquid. The impact load-time histories of these missiles impacting against reinforced concrete wall with velocity of 100 m/sec is shown in Fig. 2. Even though impacting bodies have same mass, the impact load of body with internal liquid (wet missile) is 2~3 times larger than that of body without internal liquid (dry missile).

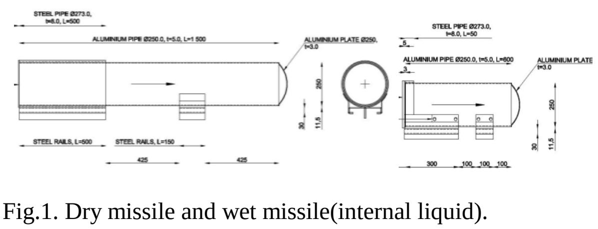
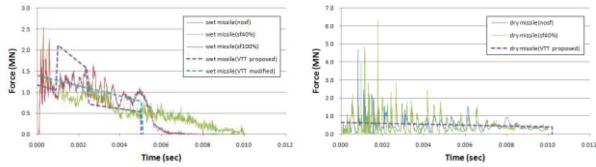


Fig.1. Dry missile and wet missile(internal liquid).

The impact load of body impacting to rigid wall, with internal liquid and the impact load of body with equivalent mass and same impact velocity are computed by general purpose finite element program ABAQUS. The impacting body is modeled as conventional finite elements and the internal liquid in impacting body is modeled by Eulerian method in which the extremely large deformation is possible. Impact analysis is performed by coupled Eulerian-Lagrangian method. The impact load-time histories of VTT impact tests are computed by using ABAQUS and shown in Fig. 2[2]. Likewise the impact loads proposed by VTT, the computed and averaged impact load of body with internal liquid is much higher than that of body without internal liquid. It is thought that this phenomenon results from mass flow as mentioned in the paper of VTT.



(a) wet missile (b) dry missile

Fig.2. Comparison of impact load-time histories.

3. Safety evaluation on NPP crashed by aircraft

A double containment type nuclear power plant is target structure and modeled as shown in Fig. 4. In this study, to compute the impact loads effectively and quickly, according to the methods of modeling the aviation fuel in large civil aircraft, only the outline of nuclear power plant is modeled and rigid body condition is given.

The target aircraft of the impact analysis is B767-400. Because aircrafts are very complex structures, it requires many costs and efforts to do realistic model. The exterior shapes such as fuselage, main and tail wings which would contribute the rigidity of aircraft is modeled as shell elements. Total mass of the aircraft model is almost consistent with the maximum takeoff weight (the maximum weight including fuel, passengers and cargo) of B767-400, 204 ton. The elastic modulus (stiffness) and yielding stresses also was determined by trial and errors so that the computed contact force-time history would be similar to the impact load-time history proposed by Takeuchi [3] by using Riera's formula [4] when the B767-400 aircraft collides on an rigid wall with a speed of 150 m/sec. The shear failure criteria on aircraft material failure has been applied.

The maximum amount of aviation fuel of large civil aircraft B767-400 is about 25 % of MTOW(maximum take-off weight: 204 ton). The aviation fuel is stored in central fuel tanks in fuselage and auxiliary tanks in main wings. To consider the effect of aviation fuel at the event of impact, it requires the detailed shape and material property information of fuel tanks as well as the aircraft. In this study, however, it is assumed that the all fuel is stored in the tanks of main wings.

There is SPH (smooth particle hydrodynamics) method as well as aforementioned CEL method in modeling liquid which may have extremely large deformations in the aircraft impact analyses. It requires much more computation times and costs with immense d.o.f. to compute accurate impact load with CEL method. SPH method give a little less accuracy results but more efficiently with simple model and fewer d.o.f. compared to CEL method. In the safety assessment of nuclear power plant crashed by aircraft, the aviation fuel is modeled by using SPH method.

To evaluate the effects of aviation fuel quantitatively, three aircraft models with/without fuel are used and summarized in Table I.

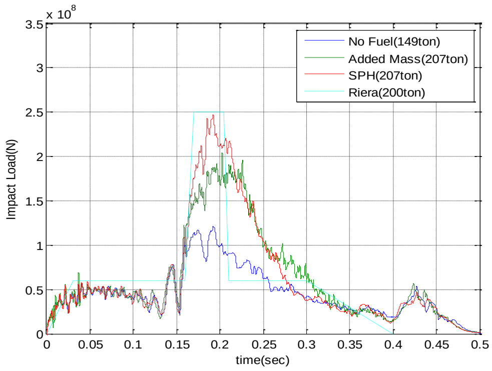
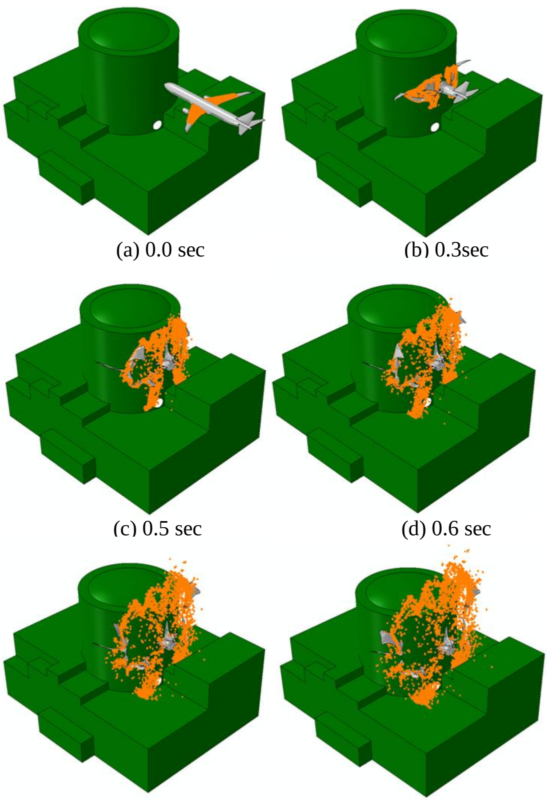


Fig.3. Comparison of impact load-time histories.



(a) 0.0 sec (b) 0.3sec

(c) 0.5 sec (d) 0.6 sec

(e) 0.7 sec (f) 0.8 sec

Fig.4. B767-NPP impact sequences.

The impact load-time histories of B767-400 crashed to NPP with an impact velocity of 150 m/sec are shown in Fig.3. The deformation and fuel dispersal sequences are shown in Fig.4. The maximum impact load of the model considering fuel is 180 MN and 245 MN for added mass model and SPH model respectively, while the impact load proposed by Takeuchi[3] using Riera approach[4] is 250 MN. However impact load of model excluding the fuel weight is computed as only 120 MN, there is a big difference to the model which is considering the fuel. The dispersal of fuel begins at time 0.25 sec with initial velocity of more than 200 m/sec as the wings (fuel tanks) begins to rupture. The initial fuel dispersal velocity might be reduced rapidly in the air, but it can be useful for the evaluation of fuel dispersal as an initial value.

Table I: Aircraft crash analysis models

case	Aircraft	Fuel	Impact mass	Remark
1	•149 ton •33,000 nodes •66,000 elems	-	149 ton	No Fuel
2	•207 ton •same nodes and elems •Increased wing mass	-	207 ton	Added Mass
3	•149 ton •same as case 1	•58 ton •97,000 SPH	207 ton	SPH

4. Conclusions

If the internal liquid weighs 60 % of total weight, then the peak impact load would be 3 times higher than that of mass-equivalent impacting body. The maximum amount of aviation fuel of large civil aircraft is about 25 % of total weight, and the impact load of model including liquid model is evaluated as about 25 % higher than that of the mass-equivalent model.

And the impact load of the model excluding the fuel weight, i.e., not considering the fuel at all results in 50% fewer than that of model including fuel. Therefore it concludes that the fuel must be considered in the way of liquid modeling or equivalent added masses. There is no differences between the duration times in each impact load-time histories. The momentums of two model (case 2 & 3) are the same and the difference in impact load is due to the mass flow. Therefore the impact load-time history might depend on the stiffness and yielding stresses of fuel tanks in main wings or fuselage.

Also it seems to be possible to make more reasonable scenario of the assessment of fire resistance of nuclear power plant exposed to aircraft fuel fire by introducing appropriate velocity and dispersal model of SPH nodes at some given time.

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