# Evaluation of Impact Force of Missile Filled with Fluid

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## 1. Introduction

After the terrorist attack on the World Trade Center using aircraft in New York City in 2001, safety assessments of nuclear power plant (NPP) structures subjected to impact force have been actively performed. However, the effect of the fluid on the impact force has not been considered when the safety assessments are performed. In this paper, the effect of the fluid on the impact force was evaluated using the commercial software LS-DYNA. In order to verify the proposed finite element (FE) models, the impact force and impulse of the missiles filled with the fluid (wet missile) were investigated, and the analysis results were compared with the force plate tests conducted by VTT laboratory in Finland [1]. A parametric study was performed to evaluate the impulse as per the position filled with the fluid and the impact velocity. The impulses of the wet missiles obtained from the parametric study were compared with those calculated by the modified Riera function [2].

## 2. Verification of finite element models

In order to verify the proposed FE models, the analysis results were compared with the force plate tests, FP16 and FP17, performed by VTT laboratory in Finland [1]. In the force plate tests, the impact force-time histories were investigated to evaluate the effect of the fluid on the impact force. The impulse-time histories were obtained by integrating the impact force-time histories. Table I summarizes the test and analysis results. The impulse on the force plate system showed a difference of 0.77% for FP16 and 0.13% for FP17 between the test and analysis. As a result, the analysis results using the proposed FE models agreed well with the test results.

Table I: Summary of test and analysis results

| Case | | Initial momentum of missile (kN.s) | Impulse on force plate system (kN.s) * | Impulse/ Momentum |
|---|---|---|---|---|
| FP16 | Test | 5.59 | 6.47 | 1.16 |
| | Analysis | 5.59 | 6.42 | 1.15 |
| | Difference | 0.00% | 0.77% | 0.86% |
| FP17 | Test | 6.55 | 7.59 | 1.16 |
| | Analysis | 6.55 | 7.58 | 1.16 |
| | Difference | 0.00% | 0.13% | 0.00% |

* Impulse on force plate system measured at impact end time

## 3. Parametric study using missile filled fluid

The proposed FE models reliably predicted the impact force and impulse of the wet missiles. In this section, a parametric study was performed to evaluate the impulse as per the position filled with the fluid and the impact velocity. The total mass of the wet missiles used for the parametric analyses was 51.5 kg including 26.4 kg of the fluid. The parametric analyses were performed using the two different wet missiles with the six different impact velocities, respectively. Fig. 1 shows the two different wet missiles which are modeled as per the position filled with the fluid. The fluid was filled in the front and middle parts of the wet missile. The six different impact velocities ranged between 100 m/s to 150 m/s.

(a) Wet missile filled with fluid in front part

(b) Wet missile filled with fluid in middle part

Fig. 1. FE models of two different wet missiles

The impulses obtained from the parametric study with the initial momentums of the wet missiles are summarized in Table II. Fig. 2 shows the impulse/momentum ratios corresponding to the different impact velocities for the wet missiles filled with the fluid in the front and middle parts, respectively.

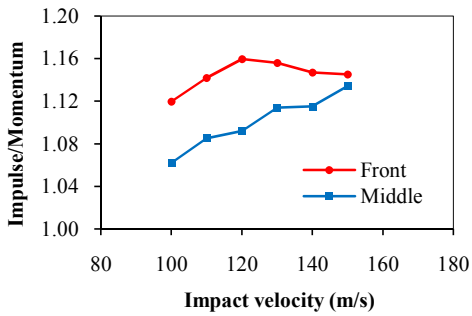
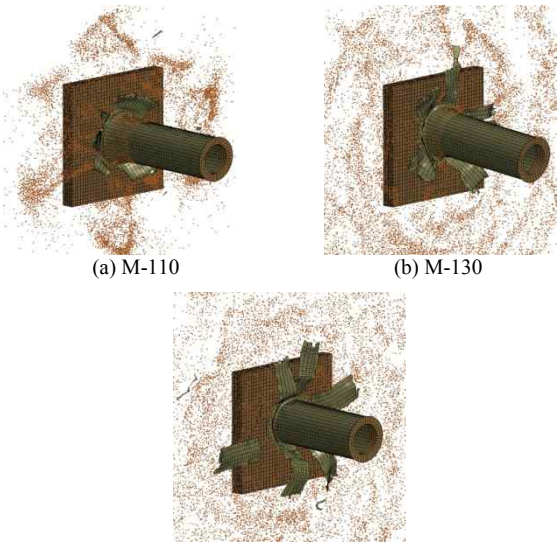



Fig. 2. Impulse/momentum ratios corresponding to different impact velocities

In the case of the wet missile filled with the fluid in the front part, the impulse/momentum ratio increased as the impact velocity increased from 100 m/s to 120 m/s, while the impulse/momentum ratio decreased as the

impact velocity increased from 120 m/s to 150 m/s. In the case of the wet missile filled with the fluid in the middle part, the impulse/momentum ratio increased as the impact velocity increased. It was because the fluid quantity which was impacted on the force plate increased as the impact velocity increased as shown in Fig 3. Overall, the impulse/momentum ratios of the wet missiles filled with fluid in the front part were larger than those of the wet missiles filled with fluid in the middle part.



(a) M-110 (b) M-130

(C) M-150

Fig. 3. Failure shapes of wet missiles filled with fluid in middle part

## 4. Comparison of parametric study results with modified Riera function

The impulses of the wet missiles obtained from the parametric study were compared with those calculated by the modified Riera function [2]. The modified Riera function is given by

$$F(t) = P_c[x(t)] + \alpha_r \mu [x(t)] V^2(t) \qquad (1)$$

where, $P_c$ is the load necessary to crush the fuselage at the impact interface (Axial strength), $\alpha_r$is a coefficient determined experimentally ($\alpha_r$ = 0.9), $\mu(x)$ is mass per unit length of the uncrushed portion, $V$ is velocity of the uncrushed portion, and $x(t)$ is the distance from the nose of the aircraft. In this study, the crushing load $P_c$ was calculated based on two different deformation mechanisms: folding and splitting mechanisms.

The impulses of the wet missiles obtained from the FE analysis and the modified Riera function are compared in Table II. It was observed that the impulse/momentum ratio by the FE analysis was larger than that by the modified Riera function up to 23.1% when the fluid was filled in the front part of the missile. When the fluid was filled in the middle part, the impulse/momentum ratio by the FE analysis was larger than that by the modified Riera function up to 20.8%. It can be concluded that the modified Riera function underestimated the impulses of the wet missiles filled with the fluid in the front and middle parts for the impact velocities of 100 m/s to 150 m/s.

Table II: Comparison of impulses of wet missiles filled with fluid in front and middle part

| Analysis case | Initial momentum of missile (kN.s) | $Impulse_{FEA}$ (kN.s) | $Impulse_{Riera}$ (kN.s) | $Impulse_{FEA}$/ Momentum | $Impulse_{Riera}$/ Momentum |
|---|---|---|---|---|---|
| F-100 | 5.150 | 5.766 | 4.871 | 1.120 | 0.946 |
| F-110 | 5.665 | 6.469 | 5.339 | 1.142 | 0.942 |
| F-120 | 6.180 | 7.167 | 5.821 | 1.160 | 0.942 |
| F-130 | 6.695 | 7.740 | 6.295 | 1.156 | 0.940 |
| F-140 | 7.210 | 8.270 | 6.763 | 1.147 | 0.938 |
| F-150 | 7.725 | 8.847 | 7.234 | 1.145 | 0.936 |
| M-100 | 5.150 | 5.470 | 4.926 | 1.062 | 0.957 |
| M-110 | 5.665 | 6.148 | 5.392 | 1.085 | 0.952 |
| M-120 | 6.180 | 6.749 | 5.860 | 1.092 | 0.948 |
| M-130 | 6.695 | 7.459 | 6.317 | 1.114 | 0.944 |
| M-140 | 7.210 | 8.041 | 6.784 | 1.115 | 0.941 |
| M-150 | 7.725 | 8.761 | 7.256 | 1.134 | 0.939 |

## 5. Conclusions

The effect of the fluid on the impact force was evaluated in this study. Based on this study, the following conclusions have been obtained:

(1) The impulse/momentum ratios of the wet missiles filled with fluid in the front part were larger than those filled with fluid in the middle part. The difference was 5.5%, 5.3%, 6.2%, 3.8%, 2.9% and 1.0% for the impact velocities of 100 m/s, 110 m/s, 120 m/s, 130 m/s, 140 m/s, and 150 m/s, respectively.

(2) The impulse/momentum ratios of the wet missiles by the FE analysis was larger than those by the modified Riera function up to 23.1% and 20.8%, respectively, when the fluid was filled in the front and middle parts. The modified Riera function underestimated the impulses of the wet missiles.

(3) The effect of the fluid on the impact force should be considered to predict the reliable behavior when the safety assessments of the NPP structures under the impact loading are performed.

## REFERENCES

[1] F. Tarallo, J. M. Rambach, 2013. Some lessons learned from tests of VTT impact program, Phase I and II. Transactions of the 22th International Conference on Structural Mechanics in Reactor Technology (SMiRT 22), Div.V-16.

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