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EFFECT OF THE FLUID ON THE IMPACT FORCE OF THE WET MISSILE

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In this paper, the force-time histories of soft missiles, with and without filled water, impacting the target wall were investigated using finite element analysis. The force plate tests, with a dry missile (test FP8) and a wet missile (test FP16) carried out by Technical Research Centre of Finland (VTT), were used. The numerical analysis results were verified by comparing with those of experiments. A parametric analysis with different missile velocities was also performed to investigate the force-time history and impulse of the missile impact on target plate. Based on a comparison with the Riera approach, the coefficients were proposed to modify the Riera function. The analysis results show that, the Riera function accurately predicted the impact force time history in the case of the dry missile. However, in the case of the wet missile, the coefficients α from 1.24 to 1.45 are recommended to be added to the second term of the Riera function in the case in which the impact velocity is in the range of 70 m/s to 200m/s.

Keywords: Impact loading, Riera function, Dynamic analysis, Fluid effect, Fluid-structures interaction, LS-DYNA.

1 INTRODUCTION

Riera (1968) proposed a formula to evaluate the force-time relationship of a deformable projectile impact. However, that equation did not consider the effect of fluid in the case where the projectile contained fluid inside. In this study, the effect of fluid on the impact loading function was evaluated. The models of soft missiles impacting a steel force plate were fully modeled. Based on the parametric analysis, the modified Riera function was proposed.

2 FINITE ELEMENT ANALYSIS

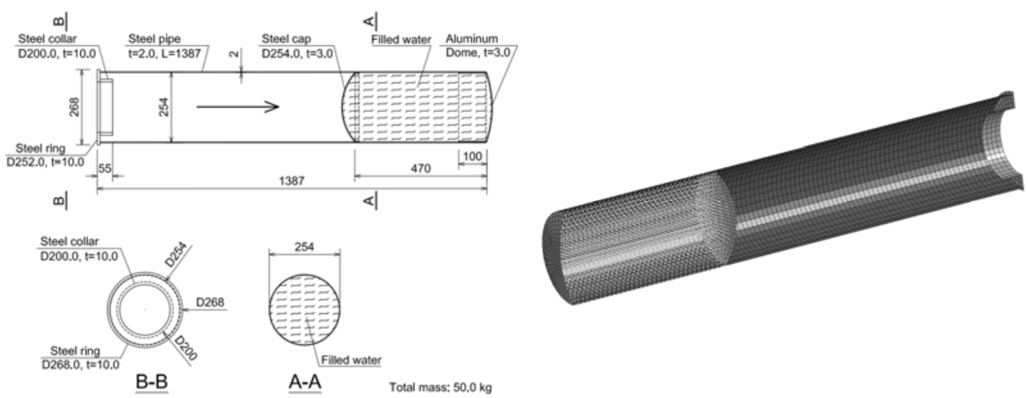
The force plate impact tests with the wet missile (FP16) used in this study were carried out by VTT Laboratory in Finland (Tarallo and Rambach 2013). LS-DYNA was used for analysis. The target, missile, and test frame were modeled separately and assembled subsequently to develop the full model. Table 1 shows the properties of the materials used in this study.

2.1 Finite Element Model

The geometry of the wet missile is shown in Figure 1a. Figure 1b shows the FE model of the missile. The shell element was used to model the steel pipe, steel dome, steel end cap, and aluminum head dome. The filled water was modeled using SPH element. Figure 2a shows a test setup of a steel force plate and support system. The force plate, back plate, and transducers were modeled using a solid element as shown in Figure 2b. The support frame was modeled using shell element, whereas the beam element was used to model the back pipes. The fixed boundary condition was applied to the back end of the back pipes. The option *AUTOMATIC_NODES_TO_SURFACE was used for the missile-target contact. The elastic plastic with kinematic hardening material model (MAT#003) was used to model the behavior of the steel and aluminum.

Table 1. Material properties.

Material	Modulus of elastic *E* (GPa)	Poisson Ratio ν	Density ρ (kg/m^3)	UCS (MPa)	UTS (MPa)	Failure Strain (%)
Stainless steel	205	0.3	7,950	410	410	10
Carbon steel	200	0.3	7,850	500	500	20
Aluminum	70	0.1	2,700	230	230	30

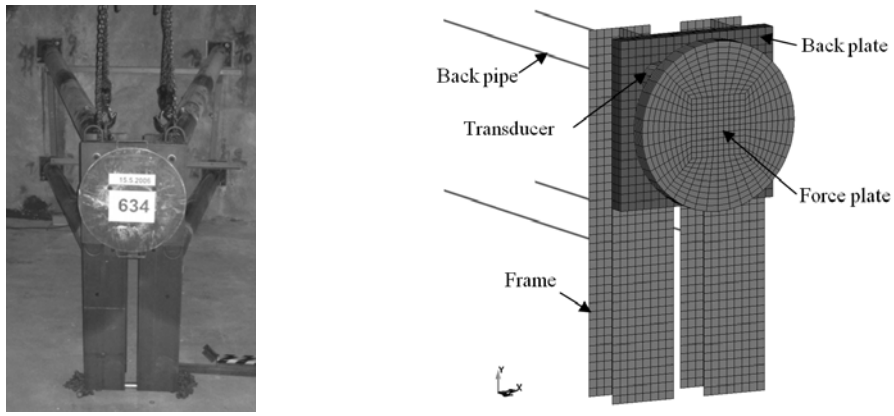


(a) Geometry. (b) FE model.

Figure 1. The wet missile.

2.2 Verification of Analysis Results

Figure 3 shows a comparison between impact force-time histories obtained from the test and FEA. The force-time history curve closely matched the test, although the oscillation of the analysis curve was slightly different as compared to the test curve. The analysis predicted the impulse accurately with an error of 0.11%, as shown in Figure 4. As a result, the developed finite element model of the wet missile impact on steel plate reliably predicted the impact force-time history and impulse.



(a) Test setup. (b) FE model.

Figure 2. Force plate and support frame.

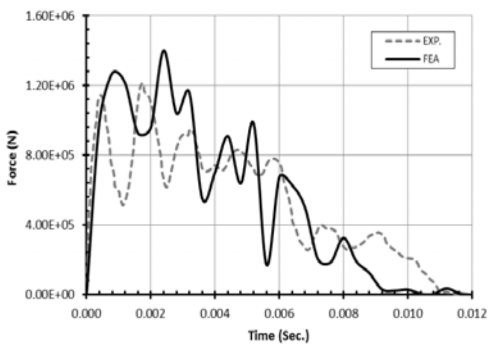


Figure 3. Comparison of impact force.

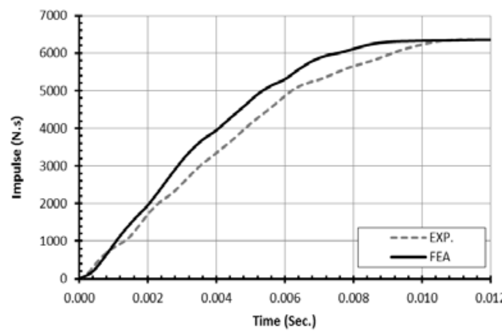


Figure 4. Comparison of impulses.

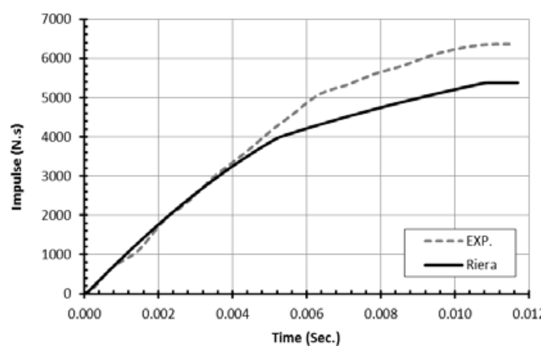


Figure 5. Comparison of impulses-time history.

3 MODIFICATION OF RIERA FUNCTION

A parametric study was carried out with different velocities from 70 m/s to 200 m/s. Based on the comparison of impact force, the modified Riera function was proposed.

3.1 Riera Function

According to Riera, the impact force $P(t)$ of a deforming or crushing projectile can be obtained using the following equation (Riera 1968):

$$P(t) = P_c[x(t)] + \mu[x(t)]v^2(t)\,, \quad (1)$$

where $P_c[x(t)]$ is the crushing force, $\mu[x(t)]$ is the mass per unit length of the missile, and $v(t)$ is the velocity of the uncrushed part of the missile. The crushing force can be calculated using the equations presented in the work of Reid (1993) and Jones (2011) based on the different deforming mechanisms.

3.2 Modified Riera Function

The impulse comparison in Figure 5 shows that there was a major difference between the total impulse obtained from the Riera method and the experiment. To predict the accurate impact force for the wet missile impact, the Riera equation should be modified by adding a coefficient α into its second term as follows:

$$P(t) = P_c[x(t)] + \alpha\mu[x(t)]v^2(t)\,. \quad (2)$$

The coefficient α was determined such that the final impulse of the Riera function corresponded to an equal value of FEA. The comparison in Table 2 shows that the coefficient α is in the range of 1.24 to 1.45.

Table 2. Comparison of impulse (N.s) between FEA and Riera approaches.

Method	**Impact velocity (m/s)**					
	70	**100**	**130**	**160**	**180**	**200**
FEA	4,030	5,880	7,340	9,090	10,800	12,900
Riera approach	3,510	4,990	6,460	7,900	8,890	9,840
Coefficient α	1.45	1.35	1.24	1.235	1.28	1.30

4 CONCLUSIONS

A reliable nonlinear finite element model of the soft missile impact on a target wall was developed. The analysis result was verified by comparing with that of experiment. A parametric study with different impact velocities was performed to investigate the force-time history. In order to consider the fluid effect of the wet missile on impact force, the recommendation was to modify the Riera equation by adding a coefficient α in the range of 1.24 to 1.45 into the second term of the right-hand side of this equation.

Acknowledgments

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