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Moving Path Analysis of a Cannonball Colliding onto Water

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Abstract. When a cannonball collides onto water, it can ricochet several times because normal force is generated larger than the weight. In order to determine the moving path, an analysis is done to calculate the position and velocity of the cannonball and the force acting on the cannonball using a finite element method. It is shown that the cannonball motion depends on the initial conditions such as cannonball shape, firing velocity, and firing angle.

Introduction

Some firing tests of cannonballs without explosive power are done onto sea water. In the tests, they can ricochet at the water surface. Understanding ricocheting is important to set an evacuation zone during firing tests for safety. In order to improve the safety of firing test environment, it is necessary to analyze the paths of ricocheting cannonballs.

The purposes of this study are to predict the moving path of a cannonball fired to water and also to prevent possible accidents against civilians by setting a safety zone which contains the ranges of cannonballs sufficiently enough.

Theoretical Background

When a cannonball collides onto water, a reactive force is generated depending on the incident angle and velocity. If the resulting force in the vertical direction is larger than the weight of the cannonball, the cannonball is lifted up. This is called a ricochet phenomenon or bouncing. [1] Fig. 1 shows a 155mm high-angle cannon.

Fig. 1 155mm high-angle cannon [2]

Collision with water implies collision of a solid body onto fluid. Assuming that the fluid is non-viscous and incompressible, the governing equation can be derived. The pressure and momentum on the cannonball surface during collision can be determined using proper boundary conditions and a source method. In the source method, sources are distributed along the centerline of the cannonball. The source strengths of the elements are determined to satisfy the body shape. The governing equation and the boundary conditions are as follows [3-4].

Governing equation : $$\nabla^2\Phi = 0 \tag{1}$$

Boundary condition on the body surface : $$-\nabla\Phi\cdot\nabla\vec{e_n} = \vec{V_E}\cdot\vec{e_n} \tag{2}$$

Boundary condition on the effective water : $$\vec{V_s} = (C_w - 1)\vec{V_p}\cdot\vec{k} = \frac{\partial\Phi}{\partial Z}(x,y,0)\cdot\vec{k} \tag{3}$$

$$\Phi = 0$$

$$C_p = \frac{(P-P_\infty)}{(1/2)\rho_\infty V_\infty{}^2} = 1 - \frac{|\nabla\Phi|^2}{V_\infty{}^2} = \frac{2}{V_\infty{}^2}\left[\frac{\partial\Phi}{\partial t} + (\vec{V_E}\cdot\nabla\Phi) - \frac{\nabla\Phi^2}{2}\right] \tag{4}$$

where Φ is a velocity potential, $\vec{e_n}$ is an unit normal vector, $\vec{V_E}$ is an entry velocity, $\vec{V_s}$ is an effective water surface velocity, C_w is a wetting factor, $\vec{V_p}$ is a velocity of the deepest point on the body, C_p is pressure coefficient, P_∞ is a pressure in the freestream, ρ_∞ is a fluid density and V_∞ is a velocity of the body.

From equation (4), impulsive force and moment can be calculated. [5] The ricochet of a cannonball is caused by the vertical pressure resulted from the collision of a cannonball which is partially submerged. The total hydro-dynamic lift force on a sphere was derived in [6]. The equation of motion for a sphere which is partially immersed in water was obtained in [7].

Analysis and results

In order to analyze the moving paths, MATLAB and ANSYS were used with a source and finite elements method. The impulse was obtained when the cannonball collides onto the water.

Fig. 2 shows the trajectory of a cannonball during collision for the water angle 1°. The initial velocity was 928m/s, the firing angle was 1° and the initial height was 5m. The cannonball went under the water at around 9.7-10km, and ricocheted 4 times.

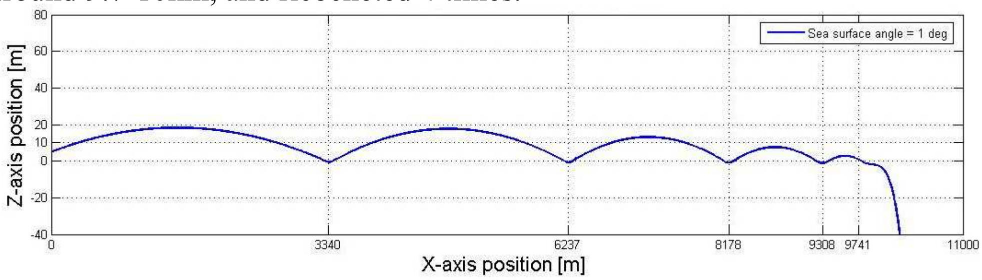

Fig. 2 Trajectory of a cannonball X-Z plane

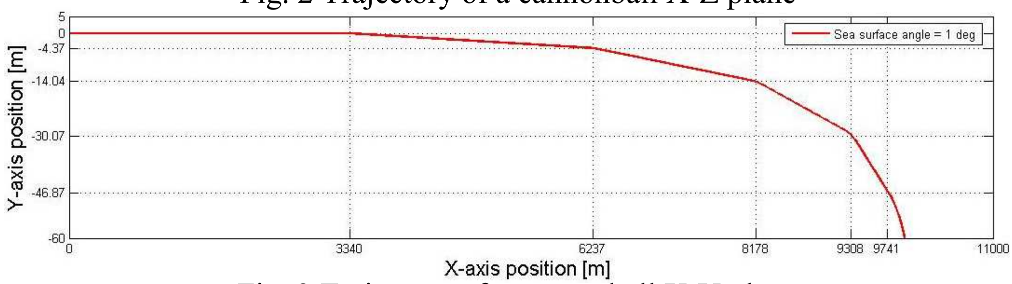

Fig. 3 Trajectory of a cannonball X-Y plane

Fig.3 shows the trajectory of the cannonball in the X-Y plane. The lower X-direction velocity the cannonball has, the higher Y-direction velocity of the cannonball is resulted. The Y directional velocity occurs due to the spinning of the cannonball.

Fig. 4 shows the 3D design of a cannonball and water. The incident angle was set at 5° to show the movement more clearly. The material of the cannonball was copper alloy and frictional setting between the cannonball and water was applied.

Fig. 5 shows the motion of a cannonball colliding onto water. The initial velocity of the cannonball was 900m/s and the spin rate was 125rad/s. The figure shows water splashing and ricocheting of the cannonball. The analysis of a cannonball colliding at a high velocity yielded the ricocheting and the stress on the cannonball shell.

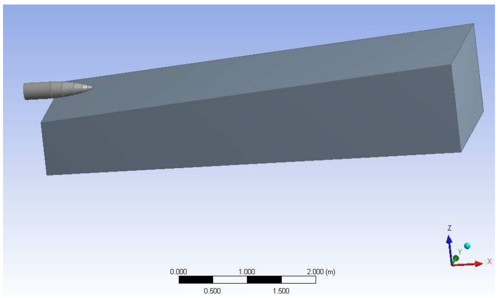

Fig. 4 3D design of a cannonball and the water

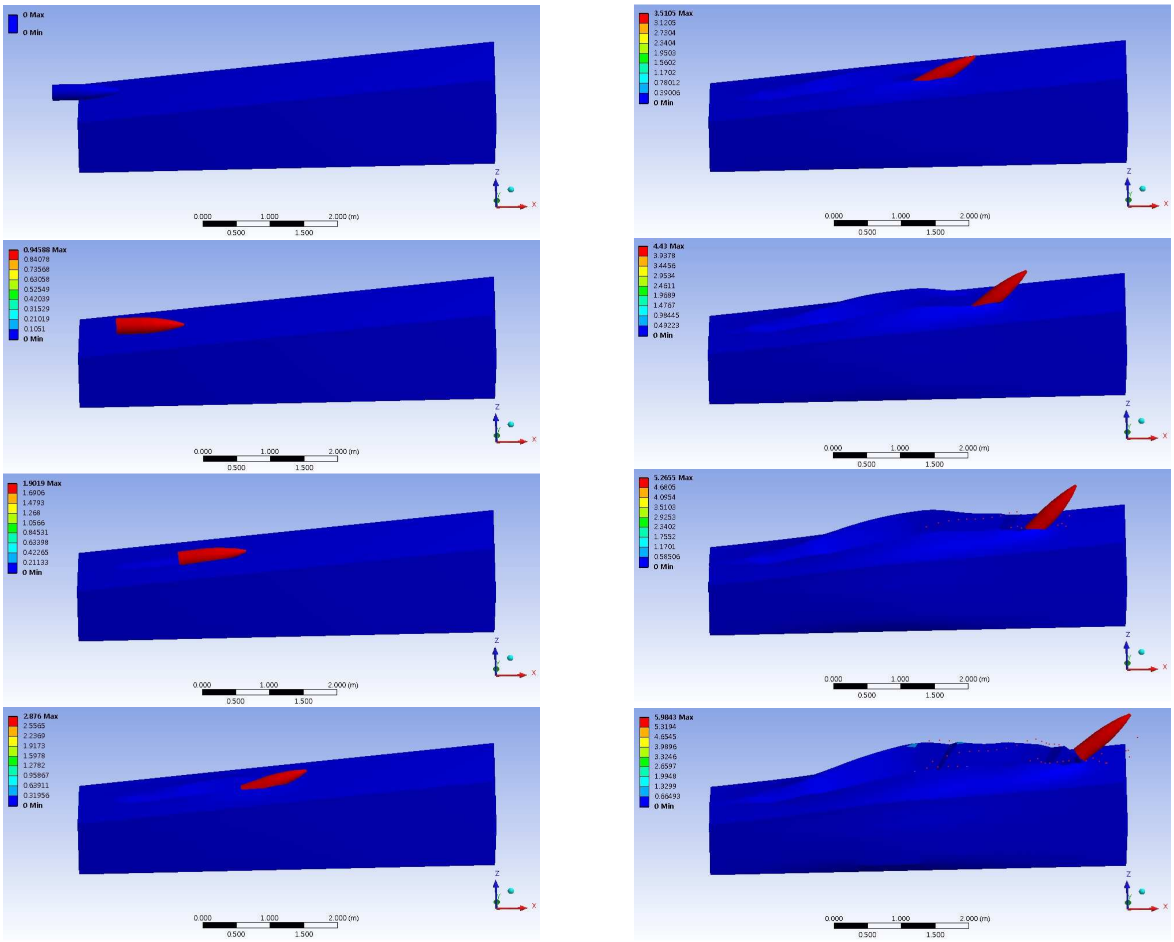

Fig. 5 Movement of a cannonball colliding onto water

Fig. 6 shows the instantaneous velocities of a cannonball in the X, Y, Z directions, respectively. In these results, the X directional velocity decreases, and the Y directional velocity is formed due to the spinning. The Z directional velocity increases, which means the occurrence of a ricochet. The spikes in the figure seem calculation errors in the finite element analysis.

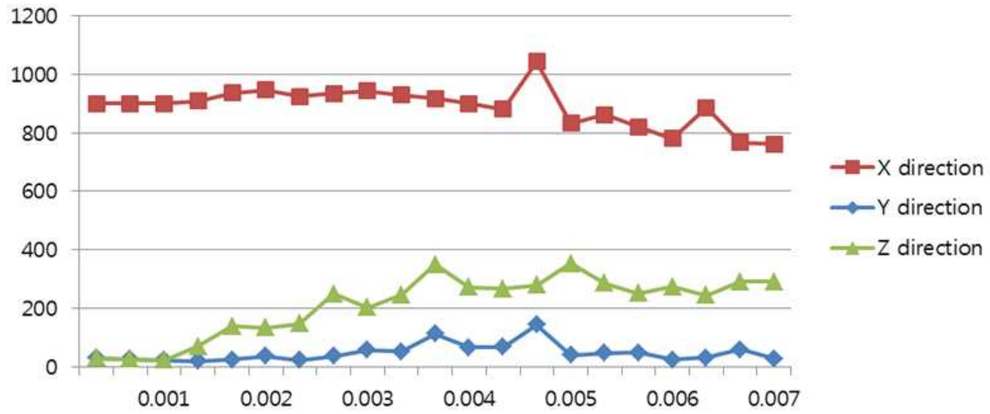

Fig. 6 Instantaneous velocities in X, Y, Z directions of a cannonball

Conclusions

When a cannonball collides onto water, an analysis was done to predict the moving path and the ricocheting of the cannonball. It was shown that the cannonball motion depends on the initial conditions such as cannonball shape, firing velocity, firing angle and so on. The accuracy of prediction of a moving path relies on the accuracy of cannonball motion and the model of the water. The moving path analysis enables to set a safety zone in cannonball firing tests against water and to perform better firing tests. For future study, the dynamic movement of a cannonball with its stress changed due to the reacting force will be done.

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