

Dynamic analysis of autonomous risk avoidance of amphibious floating bridge based on discrete element method and physical engine

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Abstract. In this paper, based on an intelligent floating bridge, by using discrete element methods and physical engines, under the action of certain missile repulsion fields, the force process and motion path in the process of autonomous evasion of missiles are studied. Firstly, the static simulation of missile repulsion fields is carried out by using the polynomial least square surface fitting method. According to the strength of repulsion field at different times and the extrusion force between the pontoons, the kinematic equation of the pontoon is established. The equation is discretised by using a discrete element method, and the kinematic equation is obtained according to the time iteration. Then, motion analysis is carried out by using a physical engine on the basis of equation Analysis. Finally, the position parameters before and after the self-evasion missile of the floating bridge are calculated, and the simulation program is written in MATLAB. The dynamic simulation experiment of the whole evasion missile process is carried out, and the results are satisfactory.

1 Introduction

As a kind of water transportation channel, as shown in Figure 1, floating bridge is widely used in military battlefields and some special operations because of its simple structure, convenient erection and disassembly, strong mobility and geographical adaptability[1]. Because of its special working conditions, it is necessary to have the strategy to make the intelligent floating bridge evade the incoming missile through reasonable decision-making and maneuver. However, due to the short decision-making and execution time in the process of avoiding missiles, in the face of the enemy's incoming missile, if only relying on human eyes to achieve evasion, it may not be able to make the right decision in time[3].



Fig. 1. Schematic diagram of connecting floating bridge.

In addition, the collision and extrusion motion between the pontoon and the pontoon is more complex, and the steady-state position after avoiding the missile is different under different scale reverse gears, so the dynamic analysis of the pontoon in the process of autonomous risk avoidance becomes particularly important.

2 Construction of repulsion field and analysis of discrete element mechanics

In order to analyze the dynamics of the floating bridge, the pressure on the floating bridge in the gravity field generated by the incoming missile must be clarified firstly. Therefore, the repulsion field generated by the floating bridge is simulated and constructed according to the related dynamics knowledge of missile flight[2].

2.1. Construction of repulsive force field

According to the relevant knowledge of hydrodynamics, the air flow velocity distribution around the missile at a specific time t in the influence range of radius R satisfies:

$$u = \frac{\Delta p}{4\mu L} (R^2 - r^2), -R \leq r \leq R \quad (1)$$

Where ΔP is the pressure difference along the flight path, μ is the aerodynamic viscosity, and L is the distance along the flight path.

According to Bernoulli equation,

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$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} + h_f \quad (2)$$

Where α is the kinetic energy correction coefficient and h_f is the head loss.

In order to simplify the calculation, the head loss is ignored and the initial state is set to constant. For the pressure distribution in the field,

$$p + \frac{1}{2} \rho v^2 = \text{const.} \quad (3)$$

In order to simulate the real trend of pressure field, the following equations can be established in MATLAB,

$$\begin{bmatrix} R^3 & R^2 & R & 1 \\ r_0^3 & r_0^2 & r_0 & 1 \\ 3R^2 & 2R & 1 & 0 \\ 3r_0^2 & 2r_0 & 1 & 0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} P_{\min} \\ P_{\max} \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

Where P_{\max} is the maximum relative pressure at the center of the field and P_{\min} is the minimum relative pressure at the edge of the field, where is 0.

Given different maximum and minimum relative pressures, the corresponding coefficients obtained are shown in the table below.

Table 1. The values of parameters under different relative pressures.

P_{\max}	200	200	300	300
P_{\min}	0	10	0	20
a	1.19e-04	1.13e-04	1.78e-04	-1.66e-04
b	-0.0267	-0.0253	-0.0400	-0.0373
c	0	0	0	0
d	200	200	300	300

Therefore, for any point in the field, it is satisfied

$$p(x, y) = \text{polyval}(p_0, x^2 + y^2) \quad (5)$$

Where, $P_0 = [a, b, c, d]$.

For the first group of data, the force field generated is shown in Figure 2.

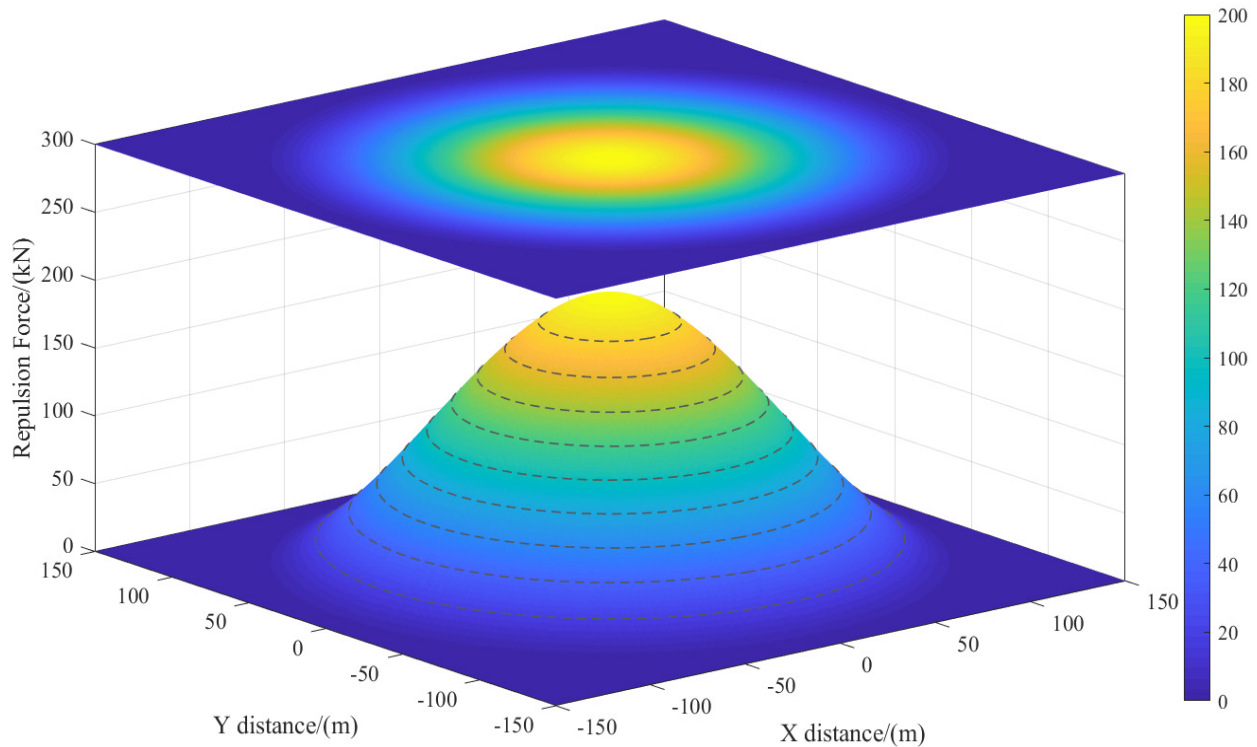


Fig. 2. Generated repulsion field

2.2. Positioning

For the bridge body in repulsion field, take it as the research object. Assuming the initial coordinate is (x_0, y_0) , and the equivalent force area is S , the repulsion force is:

$$F(x, y) = S \cdot P(x, y) \quad (6)$$

For the centre position of the field, $P(x, y) = P_{\max}$, then $F(x, y) = F_{\max}$. Then the above formula can be expressed as:

$$F_p = \frac{F_{\max}}{(x_0^2 + y_0^2)} \quad (7)$$

The azimuth of the pressure is as follows:

$$\theta_{F_p} = \arctan\left(\frac{y_0}{x_0}\right) \quad (8)$$

The resulting acceleration is:

$$a = \frac{F_p}{m} \quad (9)$$

The velocity and position coordinates are discretized, and the initial velocity of a single floating bridge is set as v_0 , and:

$$v_0 = 0 \quad (10)$$

In the dt -th time,

$$dv = a \cdot dt = \frac{F_{\max}}{(x_t^2 + y_t^2)m} \cdot dt \quad (11)$$

Therefore:

$$v_t = \int_0^t \frac{F_{\max}}{(x_t^2 + y_t^2)m} \cdot dt \quad (12)$$

So we can get the new coordinates in the next time:

$$dx = v_t \cos \theta_{F_p} \cdot dt \quad (13)$$

$$dy = v_t \sin \theta_{F_p} \cdot dt \quad (14)$$

By integrating the above formula, the coordinates of the floating bridge at any time t can be obtained.

3 Simulation and analysis of floating bridge's autonomous risk avoidance motion based on physical engine

In order to carry out the simulation test in the computer, the above formula needs to be further discretized. For the i -th moment, the magnitude of the field force on the floating bridge is as follows:

$$F(i) = \frac{F_{\max}}{x_0^2(i) + y_0^2(i)} \quad (15)$$

The azimuth is as follows:

$$\theta(i) = \arctan\left(\frac{y_0(i)}{x_0(i)}\right) \quad (16)$$

Acceleration at current time:

$$a(i) = \frac{F(i)}{m} \quad (17)$$

Get the speed of the next moment:

$$v(i+1) - v(i) = a(i) \cdot dt \quad (18)$$

Then the coordinate position of the next time is obtained:

$$x(i+1) - x(i) = v(i) \cos(\theta(i)) \cdot dt \quad (19)$$

$$y(i+1) - y(i) = v(i) \sin(\theta(i)) \cdot dt \quad (20)$$

Put the above formula into Matlab and set a specific time step for iteration. For the initial state, the force of a single floating bridge is shown in Figure 3, where F_1 is the repulsive force generated in the repulsive field, and

F_2 is the total force generated by the extrusion between the bridge and the girder. The resultant force of the two forces can cause the horizontal displacement of the girder.

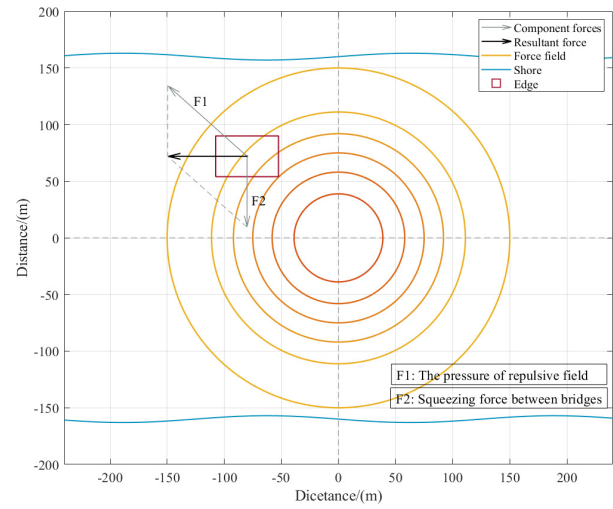


Fig. 3. Initial stress analysis of single floating bridge

Because the repulsion force in the field will decrease with the increase of the distance from the centre of the field, the total squeezing force between the bridges will also decrease adaptively, and the gravity toward the centre will increase with the increase of the displacement distance, so there is a steady point for each beam segment, which makes the force of the floating bridge tend to be stable. The final position of the floating bridge in the force field is shown in Figure 4.

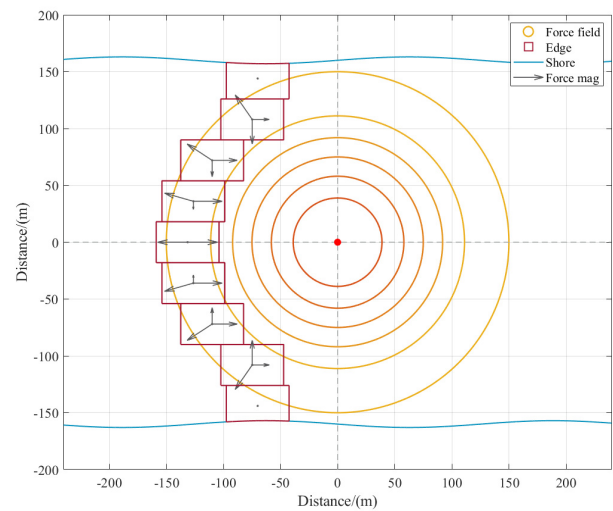


Fig. 4. The position and stress state of the floating bridge in the final state of motion

After evading the missile, the repulsion field disappears. At the same time, the squeezing force between the pontoons caused by the repulsive force field also disappears synchronously, and the pontoon will start to move again under the action of its original position gravity. This is because after the repulsion field is removed, the repulsion from the field disappears, and the squeezing force from other pontoons also disappears. For a single pontoon, it is attracted to the original position,

and gradually returns to its original position, reaching the stable connection state again.

The process is simulated in the physical engine built by MATLAB. After the repulsion field is removed, the simulation results and forces of the initial state and final state of the floating bridge are respectively shown in Figure 5. The floating bridge gradually returns to the initial position under the action of horizontal right attraction. With the decrease of the distance between the floating bridge and the initial position, the attraction received by the floating bridge is smaller, and finally it can reach the straight-line connection state again, as shown in Figure 6.

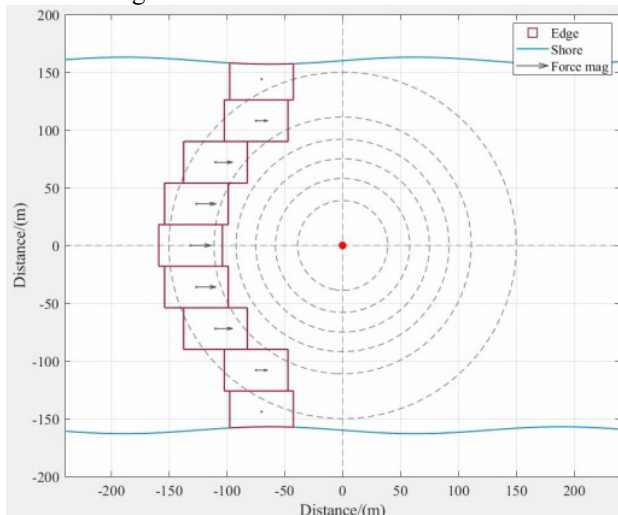


Fig. 5. Simulation results of initial state after the repulsion field disappears

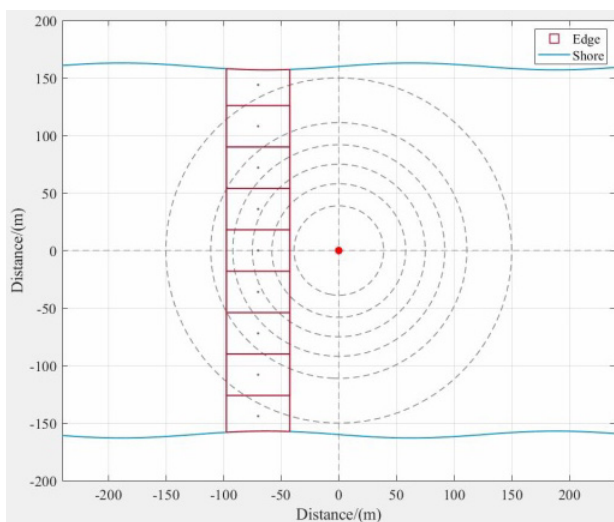


Fig.6. Simulation results of the final state after the repulsion field disappears

It can be seen that the recovery effect of the floating bridge after avoiding the missile is good, and the simulation results are consistent with the actual application results.

4 Conclusions

In this paper, based on a military intelligent floating bridge, the impact repulsion field of a missile is simulated statically by using polynomial least square surface fitting method, and the motion of the missile under the repulsion field is analysed by using discrete element method and autonomous physical engine, and the strategy of avoiding missile is studied. Finally, the modelling and simulation are carried out in MATLAB, and the simulation results are compared. It is satisfactory and helpful for the manoeuvrability and safety of the intelligent floating bridge.

Acknowledgments

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