Study on probability of ship impact against bridge out of control

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Abstract. Ship collision accidents happen occasionally, many of which are caused by ship out of control. At present, there are few studies on the probability of collision of ships with bridges out of control at home and abroad, and no mature results have been formed in all aspects of the research on the accident of collision of ships with bridges, which need further study. In this paper, the influence of wind and flow is analyzed, the drift model of wind and flow is established, and the probability of collision of out of control ships with bridges is calculated, so as to provide technical support for safe navigation of ships and anti-collision design of piers

1. Introduction
The United States published the AASHTO guidelines in 1991. When calculating the probability of ship collision, the standard regards the geometric probability density of the ship impacting the pier as a normal distribution, the standard deviation is the length of the ship, and the center line of the channel is the median position of the normal curve. The AASHTO model calculates the probability distribution of a ship's collision with the median position of the pier as the median of the normal distribution, and the probability of distribution at the position of the two pier is equal. However, in actual situations, due to the influence of wind currents, the probability of collision of two piers will not be equal. Generally, the probability of collision of piers in the launching direction is greater than that of the piers in the launching direction. This article mainly discusses the geometric probability density distribution of the ship impacting the pier under the influence of wind current and so on.

2. Establishment of mathematical model of drift
When the ship crosses the bridge, due to the influence of wind current, the ship is not sailing in the steering direction. First, establish a theoretical analysis and calculation mathematical model, analyze and calculate the trajectory of large ships and fleets passing through the bridge section under various wind and current conditions, and the drift caused by the wind current, so that the ship under the influence of wind current can be obtained The probability density of collision.

2.1. Flow induced drift
The angle between the bow and stern line and the bridge axis normal is called the yaw angle, and the angle between the flow direction and the bridge axis normal is called the flow direction angle. Then the drift of any ship under the influence of various flows can be calculated by formula (1):
\[ \Delta B_1 = S \cdot \frac{V \sin \alpha + U \sin \beta}{|V \cos \alpha + U \cos \beta|} \]  \hspace{1cm} (1)

In the formula: 
- \( S \) —— Calculate the river length (m);
- \( V \) —— Ship speed (m/s);
- \( U \) —— Flow velocity (m/s).

2.2. Wind induced drift

The drift of a ship under the influence of wind during navigation can be calculated by the following formula:

\[ \Delta B_2 = K \cdot \frac{B_a}{B_w} \cdot e^{-0.14V_a} \cdot V_a \cdot S \cdot \frac{\sin \alpha_f}{|V \cos \alpha + U \cos \beta|} \]  \hspace{1cm} (2)

In the formula: 
- \( K = \frac{\rho_w \cdot C_w}{\rho_a \cdot C_a} \) The coefficient is generally 0.038 ~ 0.041;
- \( B_a \) —— The area of wind on the hull above the water (m²);
- \( B_w \) —— Area under the hull waterline (m²), let \( B_w = L \cdot d \);
- \( V_a \) —— Ship speed in the wind (kn);
- \( \alpha_f \) —— The angle between the direction of the true wind and the normal of the bridge axis.

2.3. Total drift

\[ \Delta B = \Delta B_1 + \Delta B_2 \]
\[ = S \cdot \frac{V \sin \alpha + U \sin \beta}{|V \cos \alpha + U \cos \beta|} + K \cdot \frac{B_a}{B_w} \cdot e^{-0.14V_a} \cdot V_a \cdot S \cdot \frac{\sin \alpha_f}{|V \cos \alpha + U \cos \beta|} \]  \hspace{1cm} (3)

3. Probability density distribution under the influence of wind flow

The probability density distribution of ship collision bridge corrected by wind drift is still normal, and its shape is shown in Figure 1. However, because the wind flow is toward the pier 2, the median value of the normal distribution is not on the center line of the channel. The difference between the two is the wind flow drift. Therefore, the size of \( \mu \) in the normal distribution function is the drift caused by wind flow. The probability density distribution function under the influence of wind flow is:

\[ f (x) = \frac{1}{\sqrt{2\pi \sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \]  \hspace{1cm} (4)

In the formula: \( \sigma \) is the length of the ship.
\[ \mu = \Delta B = S \cdot \frac{V \sin \alpha + U \sin \beta}{V \cos \alpha + U \cos \beta} + K \cdot \frac{B_a}{B_w} \cdot e^{-0.14V_w} \cdot V_a \cdot S \cdot \frac{\sin \alpha_f}{V \cos \alpha + U \cos \beta} \]  

(5)

Fig 1. Probability density distribution of ship impact against bridge after correcting

It can be seen from FIG. 1 that if the drift value is positive and the ship deviates toward the pier 2, the probability of collision of the pier 1 in the launching direction PG1 is smaller than the probability of collision of the pier 2 in the launching direction PG2. Therefore, when there is an angle between the wind current and the normal of the bridge axis, the ship needs to position the ship on the side with higher water potential when crossing the bridge, so as to reduce the collision probability between the ship and the launching pier.

4. Example calculation
Take the public security bridge as an example to calculate the probability of a ship crashing out of control. According to the analysis of the traffic flow data of the Gong’an Bridge, the ships in this segment are mainly medium-sized ships with a length of 50-90m. The width of the ship is 16m, the speed of the downward ship is 8kn (4.12 m / s), and the speed of the upward ship is 10kn (5.14 m / s); wind speed is 2.4m / s, wind distribution mean square deviation is 5, flow velocity is 1.5m / s, flow direction angle is 4 ° (pointing to the north bank), flow distribution mean square deviation is 5, and yaw angle is 2 ° (Points to the south bank), the mean square deviation of the yaw angle distribution is 4. The out-of-control area considers the range of 3km in each of the upstream and downstream. In the calculation, the center of the area is selected as the out-of-control point, that is, the ship is out of control at a distance of 1500m from the bridge at the center of the channel.

Fig 2. Route planning diagram
The calculation results of each bridge pier are shown in Table 1:

| Pier | Pier width | Probability of ascending ship hitting the bridge | Probability of a downward ship hitting a bridge | Total probability |
|------|------------|-----------------------------------------------|-----------------------------------------------|-------------------|
| 3    | 8 m        | 4.90×10^{-8}                                  | 5.04×10^{-2}                                  | 5.04×10^{-2}      |
| 4    | 8 m        | 1.14×10^{-2}                                  | 3.94×10^{-12}                                 | 1.14×10^{-2}      |
| 5    | 4.5 m      | 5.58×10^{-3}                                  | 3.87×10^{-23}                                 | 5.58×10^{-3}      |
| Total|            | 1.70×10^{-2}                                  | 5.04×10^{-2}                                  | 6.74×10^{-2}      |

5. Conclusion

In this paper, the probability density distribution model of ship collision bridge modified by wind current is obtained. The difference between this model and the American ASSHTO model lies in the median position. It can be seen from the probability density distribution model of ship collision bridge corrected by wind current that the probability of the bridge pier being hit in the launching direction is larger. In the final expression of the model, the question of the value of the partial number needs to be further studied.

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