Review of Research Status and Development of Paralysis Ship Stability Criteria

Yajun Yang[1, a], Baoji Zhang[2], Cun Zeng[1], Xindi Lu[1], Siyuan Chen[1]

[1]Shanghai Maritime Univ, Merchant Marine College Shanghai 201306, China;

[2]Shanghai Maritime Univ, Marine Science and Engineering College Shanghai 201306, China.

[a]1579796540@qq.com

Abstract

Dead ship stability is one of the five failure modes in the second-generation complete stability. Compared with the first-generation complete stability, the second-generation complete stability mainly considers the effects of wave resistance and hydrodynamic characteristics on stability, so Has caused widespread concern among scholars. In order to have a clear understanding of the stability of paralyzed ships, the main calculation methods of long-term overturning probability of paralyzed ships for complete ships and damaged ships are introduced at home and abroad based on the development history and development status of paralyzed ships. And summarize the advantages and disadvantages and existing problems of existing research methods at home and abroad, as well as the influencing factors for calculating the long-term overturning probability. Finally, the future research directions of paralysis ship stability failure mode are predicted. Provide technical support for the development of second-generation complete and stable regulations in China, and improve the right of scholars at home and abroad to formulate IMO rules.

Keywords

Dead ship stability criterion; First layer of weakness criterion; Second layer of weakness criterion; Capsize probability of broken ship.

1. Introduction

When a ship encounters wind and waves while sailing at sea, it can maintain the balance of the ship through power devices and ballast systems. Crucial issue. The paralyzed ship state refers to the state that the main propulsion device, boiler and auxiliary machinery cannot operate due to lack of power. Stable failure mode of paralyzed ship. [1] It is mainly to consider the situation where the ship overturns in the free-floating state when the ship rolls resonantly in the wind and waves. The International Maritime Organization (IMO) has proposed the first generation of complete stability regulations. Although it has been recognized, it still has deficiencies. The first generation of complete stability regulations cannot reflect environmental changes, and ships are not only affected by gusts and steady winds. Will also be affected by regular waves and irregular waves, so IMO further proposed the second generation of complete stability rules. This article mainly describes the development and current situation of the stability of the paralyzed ship of the complete ship and the damaged ship, and discusses the calculation method of the stability of the paralyzed ship of the complete ship and the development trend of the stability of the damaged ship.

2. The development of paralysis stability

Ship stability can be divided into complete stability and broken cabin stability according to whether the ship is damaged. From the mid-20th century, IMO has developed a series of complete stability specifications according to different ship types, and will continue to improve in the following time.

At the 49th SLF meeting, Japan proposed a direct evaluation method for the stability of paralyzed ships; subsequently, at the 50th SLF meeting, Japan and Ireland proposed a new generation of complete stability development framework, as well as the concept of short-term and long-term evaluation. [2]

In the 51st SLF meeting in 2008, IMO and SLF formulated the first-generation complete stability specification "International Integrity and Stability Regulation 2008". The first-generation complete stability mainly focuses on a large number of overturned ships. When the ship at zero speed is affected by the steady wind and gust, the static stability curve is made by calculating the restoring arm of the ship at different inclination angles, the characteristics of the static stability parameter are studied, and the influence of the cross wind and waves is considered, Calculate the size of the wind force and the angle of inclination to determine whether the ship is capsized. [3]

In 2009, Japan, Italy and other countries clearly proposed five failure modes as three-layer evaluation methods, and proposed corresponding failure modes for parameter roll, pure stability loss, wave riding / swing, and excessive acceleration. The first level of weakness criteria, the second level of weakness criteria and the direct assessment method of stability, the types of ships that failed the first and second levels of weakness criteria are "unconventional" ship types;

In 2010, the International Maritime Organization officially named the five failure modes as the second-generation complete stability;

In 2011, the United States, Italy and other countries agreed on the first layer of weakness criteria for the stability of paralyzed ships. The selection of criteria is still controversial;

Until the 2016 IMO SDC3 meeting pointed out that the stability criterion of the second layer of the paralyzed ship should be calculated using the local linear method, and proposed amendments and criteria.

3. Research status at home and abroad

3.1 Research status abroad

The research methods on the stability overturning probability of paralyzed ships abroad are more diverse than those in China. Benlenky[3] et al. Proposed the piecewise linear method in 1993. Tomasz [4] et al. Based on LaiDyn model Carrying RoPax for simulation. Secondly, the Bayesian confidence network is used to organize the obtained results into a probabilistic meta-model. Finally, the overturning probability can be estimated, and the overturning angle and the time required for the ship to reach the overturning angle are obtained.

Yoshitaka[5] and others proposed a wave year overturning probability prediction method based on piecewise linear method and verified the scheme by Monte Carlo method, and extended it to cargo displacement, underflow, and deck water accumulation Etc. Several important influencing factors such as floating state, hydrodynamic coefficient estimation. Wind and wave statistics are also studied.

Chai W[6] et al. Proposed a probabilistic method for stochastic nonlinear roll motion and evaluated the ship's dynamics in a random ocean. Using Markov theory to study the nonlinear roll response, the single-degree-of-freedom roll motion model is extended to a four-dimensional Markov system, and the path analysis method is used to solve the high-dimensional FP equation, and the process of overturning probability with time is obtained. The effects of external excitation, roll damping and nonlinear restoring moment on the ship's overturning probability were finally compared with Monte Carlo simulation results, and the rationality of the method was verified.

Through theoretical and experimental studies, LEE DK[7] and others described the movement of damaged ships in waves, considered the effect of cabin flooding, and established a time-domain theoretical model suitable for any type of damaged or flooded ships, and Model experiments were carried out on ships with different wave heights and damaged cabins.

Tiago[8-9] and others based on the time domain theory method of the coupling problem between the ship and the water in the cabin, the method of solving the water motion characteristics of the ship and the force of the ship, discussed the movement of the passenger ship under regular waves The numerical calculation results of the complete ship state and the damaged ship state are presented, and finally compared with the actual results.

3.2 Research state in China

However, the domestic research on the stability of paralyzed ships started late, and there are not many researchers. Kun Ma [10] et al. Calculated the first layer criteria for various types of ships under different load conditions according to the piecewise linear method. , The area ratio of the area represented by the ship's recovery torque to the area represented by the wind tilting moment, and the probability of stable overturning of the paralyzed ship under the corresponding load condition, from which it is concluded that in the same ship, the larger the area ratio, the overturning probability The smaller, conversely, the greater the probability of overturning; at the same time, it also pointed out that the stability of the paralyzed ship should be above 0.09 (including this value); Jian jun Weng [11] and others proposed corresponding operation methods for the five failure modes of the second-generation complete stability. As far as the stability failure modes of paralyzed ships are concerned, the center of gravity of the ship can be lowered, the area of the wind can be reduced, and the ballast can be increased. Water and other methods to reduce the probability of overturning. Xin yu Wang [12] and others used the single-degree-of-freedom nonlinear equation of roll motion to simulate the irregularity of the ship based on the content of the second layer of weakness stability of the paralyzed ship in the first meeting of the IMO Ship Design and Construction Sub-Committee Rolling motion in wind and waves, calculating the probability of overturning of the paralyzed ship, and providing a reference for the direct evaluation method of the stability failure mode of the paralyzed ship. It is finally pointed out that it is feasible to directly simulate the ship's rolling motion in random wind and waves with a single degree of freedom. Yan hong Lu [13] and others made a brief introduction to the four failure modes, and made the first and second layer criteria evaluation for the 10,000-carton container ship respectively. As far as the quasi-level and second-level criteria are concerned, the allowable initial stability is high and the change of the roll period meets the requirements of progressive layers, but the trend is still consistent. It is also proposed that the second level of stability of paralyzed ships still needs to be improved. Xue tang Gao [14] et al. Calculated the probability of collapse of ship collapse stability for CEHIPAR2792 and C11 container ship and concluded that when the steady wind speed is less than 25m / s, the ship is unlikely to overturn, and when the wind speed is greater than 30m / s, the ship is likely to Overturning; and it is proposed that the effective wave inclination coefficient will be more accurate if the slice method is used than the empirical formula to calculate the overturning probability.

Regarding the calculation method of the probability of overturning of the paralyzed ship, there are many methods proposed at home and abroad, but the only commonly used methods are the piecewise linear method and the local linear method. The projected area on the wind side is related to the high initial stability GM. The overturning probability increases first and then decreases with the increase of high initial stability. When the projected area on the wind-side increases, the overturning probability also increases.

Regarding the probability of overturning of a damaged ship, Jia Li [15] et al. Developed a time-domain numerical simulation calculation program based on the quasi-static calculation method to analyze the ship's water intake from the beginning until the water intake is stable, and then the ship's floating state where the rolling motion tends to be stable, And taking a 3100TEU container ship as an example, the impact of the size and position of the break on the ship's roll was analyzed.

Yan shun Huang [16] et al. Established the differential equation of the roll motion of the tank-breaking water intake ship in regular waves, simulated the dynamic torque of the tank water using FLOW-3D, and solved the roll motion equation with the MATLAB The roll motion characteristics of the complete ship and the damaged ship are shown.

Fen hu Li [17] and others established a time domain model of the water intake process of the damaged ship based on the Bernoulli equation. The weighted method was used to solve the floating state parameters, and the trapezoid method was used to calculate the water intake volume. The water process is calculated in time domain, and the conclusion shows that the influent velocity first slowly increases, then decreases, and then tends to zero. During the influent process, the floating state parameter changes gently, and is related to the location of the breach and the influent time.

Zhen wang Lv[18] et al. Simplified the roll motion of the damaged ship based on the evaluation method of the stability failure mode of the complete ship, considering the two cases of symmetrical and asymmetrical water intake, and obtained these two separately The probability of overturning under the paralyzed condition is pointed out. The probability of overturning under the paraplegic condition of the complete ship can be used to evaluate the probability of overturning of the damaged ship under the paralyzed condition. The situation of asymmetrical inflow is more dangerous than the situation of symmetrical inflow.

The domestic and international researches on the probability of stable overturning of the paralyzed ship use two methods, namely, the Carlo Monte simulation method and the local linear method. After the damaged ship enters the water, the overturning probability of the ship will increase. The probability of ship overturning is greater than that under symmetrical flooding.

4. Evaluation method of stability of paralyzed ship

4.1 Crisis of the first layer of stability of paralyzed ship

The first layer of weakness criteria for the stability of paralyzed ships [10], which is composed of the meteorological criteria in the 2008 International Integrity and Stability Regulation (Part A, Rule 2.3) and the wave dip table in MSC.1 / Circ.1200 , The content of the first level of criteria is as follows:

$$\varphi_0 \le \min \begin{Bmatrix} 16^\circ \\ 0.8 \cdot \varphi_{jb} \end{Bmatrix} \quad (1)$$

$$b \ge a \quad (2)$$

In the formula, φ_0 is the heel angle under the action of steady wind, φ_{jb} is the water inlet angle at the edge of the deck, and b is the area of the two parts enclosed by the GZ curve of the unsteady wind force arm and the restoring arm.

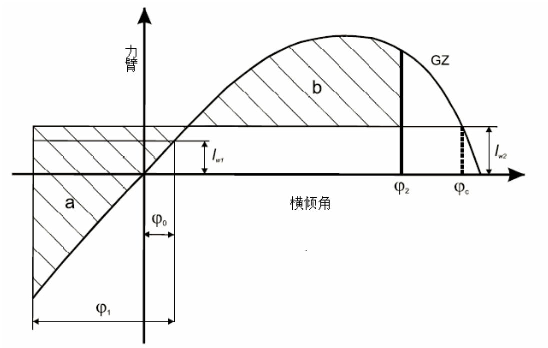


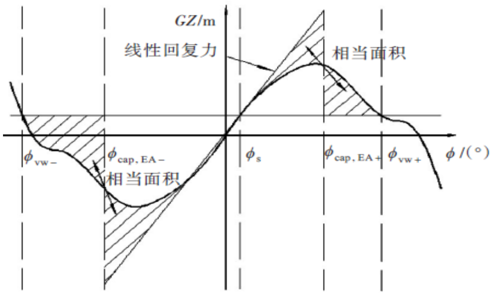
Figure 1 Strong wind and rolling

4.2 Crisis of stability of paralyzed ship

The second stratification criterion for the stability of paralyzed ships provides a conservative probability value for the ship. This probability value is obtained by weighting the weight coefficients of different sea conditions in the North Atlantic wave scatter diagram and the short-term overturning probability under the corresponding sea conditions. Calculation method See formula (3):

$$CI = \sum_{H_s} \sum_{Tz} (W(H_S, T_z), C_s(H_s, T_z, U_w)) \quad (3)$$

In the formula, $W(H_S, T_z)$ is the weighting coefficient under any sea condition, $C_s(H_s, T_z, U_w)$ is the probability of overturning of the paralyzed ship under a certain sea condition, where H_s is the high of the meaningful wave, H_s the zero-crossing period, and U_w the average wind speed. The calculation of the short-term overturning probability can refer to the local linear method provided by Italy and the piecewise linear method proposed by Japan:



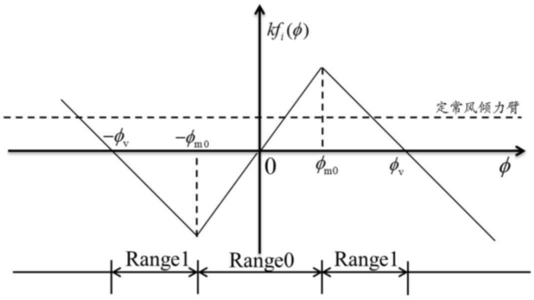


Figure 2 Local linear method Figure 3 Piecewise linear method

The simplified method of the local linear method is to draw a straight line through the origin. The slope is the slope of the tangent of the static stability curve at the static heel angle. When the areas are equal, the line segment ends.

In the local linear method, the steady wind tilting arm intersects the static stability curve at three points, from left to right are the negative residual stability vanishing angle ϕ_{VW-}, the static lateral tilt angle ϕ_s, and the positive residual stability vanishing angle ϕ_{VW+}.

The simplified method of the piecewise linear method is very different from the local linear method. The straight line whose slope is the tangent slope at the static heel angle passes through the origin. The line segments together serve as a simplified line segment of the static stability curve.

After piecewise linear in Figure 3, the restoring torque is simplified as:

Downwind:

$$kf_i(\phi) = \begin{cases} kf_0\phi; 0 < \phi < \phi_{m0}; Range0 \\ kf_1(\phi_v - \phi); \phi_{m0} < \phi < \phi_v; Range1 \end{cases} \tag{4}$$

Against the wind:

$$kf_i(\phi) = \begin{cases} kf_0\phi; -\phi_{m0} < \phi < 0; Range0 \\ kf_1(\phi_v - \phi); -\phi_v < \phi < -\phi_{m0}; Range1 \end{cases} \tag{5}$$

The slope of the segment $Range0$ is the slope of the tangent of the static stability curve at the static heel angle. The slope of the segment $Range1$ is the slope of the line connecting the end point of $Range0$ and the vanishing angle of stability.

Monte Carlo simulation is more complicated. Corresponding to each group of wind and wave conditions in the North Atlantic wave scatter plot, the gust wind speed is simulated according to formula (6), the sine waves of different frequencies and random phases are simulated according to the wave spectrum, and superimposed according to the number of simulations.

$$\begin{cases} U(t) = \sum_{i=1}^{N_w} b_i \sin(\omega_i t + \varepsilon_i) \\ b_i = \sqrt{2S_{wind}(\omega_i)\delta\omega} \\ S_{wind}(\omega_i) = K\dfrac{U_w^2}{\omega_i}\dfrac{X_D^2}{(1+X_D^2)^{4/3}} \end{cases} \tag{6}$$

The fourth-order Runge-Kutta method is used to solve the single-degree-of-freedom rolling equation, and the time domain analysis is performed. The test calculation time is set to 1h, and the probability of each overturn is assumed to be p (0 <p <1). When not many times, the probability of overturning of a paralyzed ship follows the Bernoulli distribution. In N tests, the probability of n overturning of a ship is:

$$P(n, N, p) = C_N^n p^n (1-p)^{N-n}, n = 0,1,\cdots\cdots, \quad N \tag{7}$$

When N is large enough, it is approximated to follow a normal distribution.

4.3 Probability assessment of the overturned ship′s collapsed state

In order to evaluate the probability of overturning of the damaged ship in the state of paralyzed ship, the roll motion equation of the damaged ship needs to be established, and different mathematical models are established according to the damage of the ship. A large number of time-domain simulations show that the roll of the damaged ship during the water intake stage The angle amplitude has little influence, so the influence of the influent process can be ignored. In the first type of damage condition, there is no free liquid surface in the cabin, the heel angle and the new static stability curve can be directly calculated, and the probability of overturning can be calculated according to the second-level criterion of the stability of the ship. The second type of damage needs to consider the size of the ship's water intake and the effect of free liquid surface. The third type of damage condition is the direct connection between the cabin and the seawater, which is mostly solved by CFD technology and viscous flow model.

Regarding the damage of the second type of cabin, ignoring the liquid sloshing in the cabin, the flow rate of all the breaks connected to the cabin is equal to the increment of water intake, and the break meets the Bernoulli equation, which can be obtained: the break The expressions of flow velocity with respect to the heel angle, pitch angle, and average draft, after determining the time step, we can know the flow rate at the breach within a certain period of time, and fit the function of the influent volume, using the weight increase method, iteratively solves to obtain the final liquid level height and the relevant floating state parameters of the ship at this time, and finally establishes the single-degree-of-freedom rolling motion equation of the damaged ship to find the damage under irregular wind and waves The probability of overturning the stability of the ship's paralysis.

4.4 Method overview

The first-level evaluation of the stability of the paralyzed ship adopts the mandatory meteorological criteria. The non-conventional ship needs to perform the second-level evaluation if the first-level criteria does not pass. If it still cannot pass the second-level criteria, then can enter the third level of criteria assessment.

Foreign scholar Tomasz calculated the rollover probability based on the Bayesian belief network. Such methods are usually based on a large number of statistical data, and some of the required data are obtained through numerical analysis, and some are obtained through simulation. The amount is quite large and is not suitable for setting criteria; The commonly used Monte Carlo simulation requires at least 1600 simulations under each group of wind and wave conditions, corresponding to the 272 wind and wave conditions in the North Atlantic wave scatter diagram, the calculation amount is too large, and the calculation time is too long; Later, in order to shorten the calculation time and simplify the calculation method, some scholars proposed a piecewise linear method, which has been improved a lot. Compared with the previous method, it takes less time. The method proposed by Italy and the piecewise linear method proposed by Japan are more accurate There is not much difference in the above, and compared with the piecewise linear method, it is more applicable and more concise, and it is more convenient to calculate the long-term sea state.

There are not many domestic and foreign researchers on the probability of overturning damaged ships. Due to the many cases of ship damage, when the interior of the cabin is connected to the outside of the cabin, and seawater can enter and exit arbitrarily, it is necessary to consider that the density of the seawater and the liquid in the cabin are different, there will be liquid exchange, and the location of the breach is at sea level The location will cause seawater or liquid in the tank to have very different flow rates and directions. The damage situation of such cabins is more complicated, and CFD calculation is often used; When the cabin is not connected with the outside world, and the cabin roof is below the waterline, and the entire cabin is filled with seawater, the water intake process can be regarded as a quasi-static process, and it has little effect on the ship's capsizing. The damage of the class cabin still needs to consider the influence of the free liquid level, and determine the height of the liquid level in the cabin, which is more complicated than the damage situation of the entire cabin filled with seawater.

5. Summary and outlook

Earlier, Bouguer [19] proposed the concept of stability, and gave a calculation formula with high initial stability; the concept of dynamic stability proposed by Revered Moseley[20]; the basic criteria for complete stability and meteorological criteria formulated by IMO; Subsequently, a series of new-generation complete stability development frameworks, short-term assessment and long-term assessment concepts, and five failure modes in three-tier assessment methods have been proposed and approved; After changing the name of the five failure modes, and finally entering the period when the calculation method and criterion value of the second-tier weakness criterion were proposed by all countries, the second-tier criterion for the stability of the complete ship's paralyzed ship also came to an end. Nowadays, scholars from various countries have devoted themselves to the research tide of the direct evaluation of the stability of paralyzed ships, and have also proposed a reference method for the direct evaluation of the stability of paralyzed ships. Among a large number of research methods on the probability of overturning of paralyzed ships, the single degree of freedom is considered the most in the subsequent research on the direct evaluation method, foreign scholars believe that at least five degrees of freedom (rolling-swinging-pitching-first-swinging) should be considered. In future research, multi-degree-of-freedom coupling is bound to become a trend.

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