Time-variant Reliability Analysis of Ship Grillage Structure

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***Abstract*—Material characteristics, environmental conditions and loading characteristics under the time domain features shall be taken into consideration so as to effectively evaluate the reliability of ship grillage structure. Moreover, the method of time-variant reliability serves as an effective approach to solve the problem. In the paper, based on the loading environmental features of ships during the enlistment, research has been conducted on the changing of material geometrical and mechanical characteristics with time under the corrosive action. Furthermore, on the basis of time-variant theory, the time-variant model of section modulus as well as bending strength concerning the ship grillage structure has been established, thus generating a time-variant reliability analysis method integrated with out-crossing rate and First Order Second Moment(FOSM) method. Besides, the paper analyzes the time consecutiveness of ship grillage structure reliability based on the time-variant reliability cases of certain ship grillage structure under the corrosion environment while the failure probability of the ship during the enlistment has been accurately predicted.**

Keywords-time-variant reliability; structural reliability; out-crossing rate; section modulus; bending stress; corrosion

I. INTRODUCTION

Affected by complex load during the life cycle, deck or bottom structure of the ships could bear great total longitudinal bending pressure, thus causing the flexural failure. Therefore, when it comes to the analysis on ship grillage structure strength, examination shall be conducted on bending strength [1]. Affected by storms and the ocean water, ship can unavoidably experience corrosion. As a result, the thickness of the ship grillage structure could be reduced, thus leading to the decrease of effective section modulus. In this way, the bending strength has been reduced, thereby lowering the reliability of the ships as time goes on. Hence, section modulus and bending strength of the ship grillage structure shall be seen as the random variables continuously changing with time, while time-variant reliability method is adopted for analysis.

The core of structure reliability analysis is the evaluation for the structure failure probability. In the traditional ship structure design, safety factor method has been mainly adopted for evaluation, which, however, cannot actually reflect the practical safety of the structure. For the ship structure, there are uncertainties for the loading and capacities due to the fact that the ship has been in the ever-changing ocean environment for a long time. In recent years, reliability-based design method has been universally adopted for ship structure design in the ocean engineering field, which can fully reflect the objective uncertainties existing in structure loading and capacity, thus rendering sufficient and reasonable utilization of the material. In the ocean environment, ship structure has borne complicated loading. In consideration of the time variant characteristics, Andre T. Beck [2] conducted the time-variant reliability analysis on the uncertainty structure through time-variant reliability method. Unavoidably, the ship structure could experience corrosion in the ocean environment for a long time, in which process the material performance is also degraded. Considering the influence of the ocean corrosion, M. Mejri et al. [3] conducted the analysis on the nolinear degradation with the out-crossing rate method, thus solving problem of nolinear degeneration for ship structure. C. Andrieu-Renaud et al. [4] has made some improvements in utilizing out-sourcing method to calculate the time-variant reliability, and put forward the PHI2 method for the first time. Besides, they also came up with a time-variant reliability method so as to calculate the ship bridge.

The methods mentioned above are some researches on the ship structure reliability under the time domain feature. However, in terms of the uncertainty structure, strength time variant feature caused by material feature degradation has not been taken into consideration. When it comes to the analysis on the time-variant reliability of ship structure by using the out-crossing rate, attention has only been paid to the influence of material features on ship structure under the time domain features, while there is no analysis on the strength of minimum life section concerning the dangerous section of the ship grillage.

In the paper, based on the features of the loading environment borne by the ships, time variant features of section modulus and bending strength affected by the corrosion have been taken into consideration. Besides, ship grillage structure has been selected for time variant analysis, while random time-variant model and performance function of ship grillage have been established. Moreover, out-crossing rate method and FORM method are employed at the same time, so as to figure out the reliability index. At last, a reasonable method of calculating the time-variant reliability of grillage structure has been introduced.

II. Reliability and Time Variant Feature Analysis on Ship Grillage Structure

2.1 Grillage structure operation conditions and reliability

Ship body is mainly structured by grillage structure with longitudinal stiffeners and beam. When the ship is sailing on the ocean, the neutral axis of midship section is the farthest point away from the deck and double sole. Hence, in the sagging state, deck can bear greater total longitudinal bending pressure, for which strength fracture can be caused; however, in the hogging state, the hull bottom can bear greater total longitudinal bending pressure, for which strength fracture can also be caused. Generally, the most possible damage would be pressure-caused flexural failure of the deck or hull bottom structure.

Besides the strength fracture, there is also inevitable corrosion damage due to the corrosion of storms and sea-water because the ship could be long staying in the marine environment. These corrosions could result in the reduction of ship structure thickness and decrease of effective section modulus, thus resulting in the reduction of total longitudinal bending strength, after which the ship reliability could decrease with time.

The whole structure or one part could exceed certain state, which then cannot satisfy the certain volunteer requirements of design regulation. This state is called the limit state of the structure. The reach of limit state is set as the basis for structure reliability analysis and design. Performance function of structure is constructed as：

$$Z = G(X) = G(X_1, X_2, \cdots X_n) \tag{1}$$

$\mathbf{X}=(X_1,X_2,\cdots X_n)^T$ represents the set of n random variables influencing structure functions; probability density function of performance function Z is $f_Z(z)$, while limit state performance function Z can divide the solution space into two domains; $Z>0$ refers to the safety domain; $Z<0$ means the failure domain; $Z=0$ refers to the limit state.

Based on the above analysis, state of $Z<0$ is set as the failure criteria of structure reliability, which can be defined as the failure probability in case of performance function $Z<0$:

$$P_f = P_f(Z\le 0) = \int_{-\infty}^{0} f_Z(z)dz \tag{2}$$

Reliability index β of the structure is related to failure probability:

$$p_f = \Phi(-\beta) = 1-\Phi(\beta) \tag{3}$$

Time-variant reliability of the structure aims to calculate the failure probability [5, 6] of mechanical system under the given failure criteria, in which randomness is incurred by model description (shape and material characteristics) and environment (loading).

2.2 Analysis on time-variant characteristics of grillage structure

Due to the randomness of factors influencing structure reliability, including environmental factors and loading effect, time-variant characteristics analysis shall be conducted on these factors.

1) Environmental factors

Ships are staying in ocean environment for a long time, for which there can be serious corrosion. In the water, there are mainly electrochemistry corrosion, mechanical action corrosion, microorganism corrosion, etc., which can increase with time. As a result, the thickness, width and web height of grillage structure could change, while the effective section modulus changes and the mechanical properties of materials could be further degraded. Here, the general corrosion model [7] is always adopted:

$$r(t) = r_i(t - t_0) \tag{4}$$

In the equation, $r(t)$ refers to the reduced thickness (unit: mm) within period of t, r_i means the annual corrosion rate (unit: mm/a), and t_0 indicates the guard time (unit: h) of anticorrosive material. According to relevant researches, annual corrosion rate is generally following the normal distribution. It is also assumed that within the same structure domain of the ship, the annual corrosion rate is the same.

2) Loading effect

The environment loading features borne by the ships are complicated, such as sea load, wind load, still water load. In the paper, both still water bending moment and wave bending moment are taken into consideration. When the ship sails, there would be the flexural failure of deck or bottom grillage structure due to co-effect of still water load and wave load, thus greatly reducing the reliability of the ships.

For the still water bending moment, SSC statistic analysis [9] held that it could follow normal distribution, the maximum bending moment of which can be calculated by the following equation:

$$M_s = \begin{cases} -0.065 C_w L_0^2 B_0 (C_B + 0.7), sagging \\ C_w L_0^2 B_0 (0.1225 - 0.015 C_B), hogging \end{cases} \tag{5}$$

In the equation, M_s refers to the maximum still water bending moment (unit: kN), L_0 means the ship length (unit:

m), and B_0 indicates the molded breadth (unit: m); C_B means the block coefficient and C_w refers to the wave coefficient.

Wave bending moment is provided with greater variability compared with still water bending moment. The randomness mainly comes from the storm; according to research [9], the wave load changes with wave length, wave height, ship size and the relative location between ship and wave. At present, universally adopted equation is the one provided by IACSURS11 [9]:

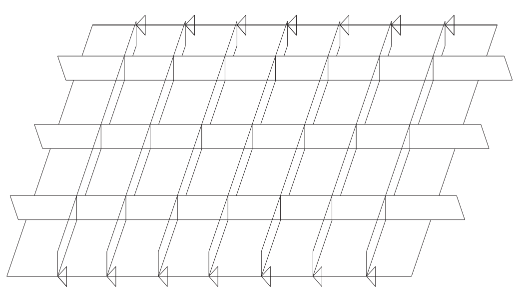
$$M_w = \begin{cases} -0.11 C_w L_0^2 B_0 (C_B + 0.7), Sagging \\ 0.19 C_w L_0^2 B_0 C_B, \quad hogging \end{cases} \quad (6)$$

In the equation, M_w represents the maximum wave bending moment (unit: kN).

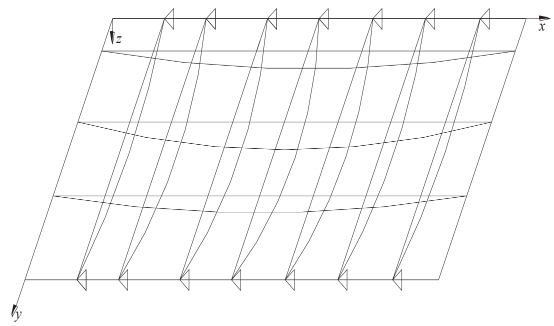
III. FORCE ANALYSIS ON SHIP GRILLAGE STRUCTURE

3.1 Simplified model of grillage structure force

Ship deck grillage is usually a set of conplane grillage, the number of which is not equal for the two directions. Direction parallel to most beams is the main direction, while the beam parallel to the main direction is the main beam; for the beam perpendicular to the main direction is the cross beam. Parallel grillage is directly bearing the external load with vertical effect, while the grillage, after the bending deformation, could transmit the load to bearing boundary. In this way, solution to the plane grillage bending elements is brought in. Figure 1refers to the loading condition of certain plane grillage,Figure 1 (a) means the grillage bearing uniform load, while Figure 1(b) represents the deformation after grillage loading.



(a) Before loading



(b)Deformation after loading

Figure 1. Loading of certain ship deck grillage

Here, certain ship deck grillage structure is simplified into the form shown in Figure 2(a), in which there are n main beams and m cross beams; the boundary condition of grillage is that the two ends of cross beam can fixed on the athwart-ship bulkhead through rigid fastening, with the two ends of main beam fixed by simply support. It is believed that external load is only effective on the main beam, and the external load borne by each beam is Q ; L refers to the length of cross beam, l is the length of main beam, and $a = L/(n+1)$ is the space between main beams; I and i_0 are cross sectional moments of inertia for cross beam and main beam. Cross beam is only playing the supporting role for main beam, for which it can only bear the node reaction R_i transmitted by main beam; however, main beam can bear external load and the counter-force of cross beam. Disconnect the main beam with the cross beam component in the node, and establish the main beam calculation model under the condition of the i th bearing distribution loading $q = Q/l$ and Node reaction R_i , with the force chart shown in the following Figure 2 (b). In consideration of that cross beam can only bear node reaction R_i , the force chart is shown as the following Figure 2 (c).

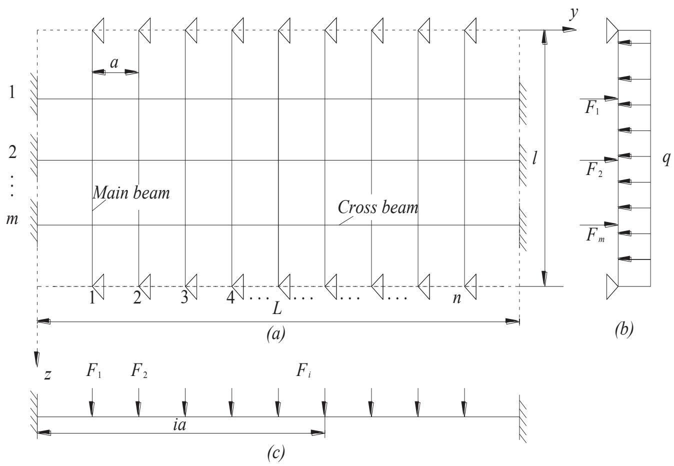


Figure 2. Simplified model of $n \times m$ grillage structure force

3.2 Minimum life section analysis of grillage dangerous section

When there is a great number of main beams of the grillage, cross beam can be transformed into elastic foundation beam for calculation. Moreover, bending theory of basic elastic beam can be adopted to solve the bending elements of cross beam; in terms of the minimum life section of dangerous section, it may be broken due to the reason that the structure could bear the maximum bending moment. Therefore, this point is taken as the reliability analysis criteria [10].

In general, maximum bending moment can appear in both the endpoint and middle point of the cross beam, for which the minimum life section of dangerous section bearing the maximum bending moment shall be found out. For cross beam, it can be transformed into the elastic foundation beam bearing uniform distribution of loading, with the two ends facing rigid fastening. The bending moment can be calculate with the following equations:

$$M_{\frac{L}{2}} = -\frac{c}{\gamma}\frac{qL^2}{24a}\chi_2(u) \tag{7}$$

$$M_{\text{端}} = \frac{c}{\gamma}\frac{qL^2}{12a}\chi_1(u) \tag{8}$$

In the equations, $\chi_1(u)$ and $\chi_2(u)$ are the auxiliary functions of elastic foundation beam.

a ——distance between main beams, $a = L/(n+1)$;

u ——parameters of elastic foundation beam auxiliary function;

c & γ ——influence coefficients

Based in equations (7) and(8), maximum bending moment of the grillage can be calculated

$$M_{\max} = \max\left\{M_{L/2}, M_{\text{端}}\right\} \tag{9}$$

Counter-force R_i on the main beam is

$$R_{\frac{L}{2}} = q\varphi_1(u) \tag{10}$$

$$R_{\text{端}} = q \tag{11}$$

In the equation, $\varphi_1(u)$ ——auxiliary function of elastic foundation beam

u ——parameter of elastic foundation beam auxiliary function

From equations (10) and (11), the maximum node reaction of grillage is

$$R_{\max} = \max\left\{R_{L/2}, R_{\text{端}}\right\} \tag{12}$$

$\chi_1(u)$, $\chi_2(u)$ and $\varphi_1(u)$ can be found out by checking auxiliary function of elastic foundation beam with rigid fixing two ends. Through calculation, the maximum bending moment and node reaction can be calculated, thereby finding out the point of minimum life section of dangerous section. The point shall be taken as the basis for time-variant reliability analysis, thus getting the reliability index of grillage.

IV. Time-Variant Reliability Calculation of Ship Grillage Structure

4.1 Section modulus time-variant model

For ship grillage structure, the following Figure 3(I-shaped section) is usually adopted: B refers to the width of the upper and lower edge strip, δ is the thickness, H is the web height, b is the web breadth, and the unit is mm .

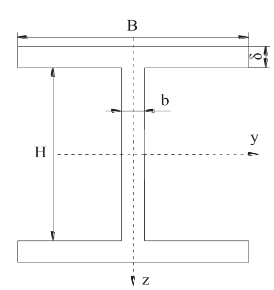


Figure 3. Symmetric I-shaped section

In analyzing the influencing factors of structure strength, material properties can change with time. Under the corrosion conditions, the edge strip thickness, breadth and web height of I-shaped section can decrease with time, thus reducing the effective section modulus. Seawater corrosion can exert the most obvious influence on the thickness of section edge strips. Therefore, in consideration of the influence of single element change on section modulus, edge strip thickness of I-shaped section can be seen as the time-dependent random variable $\delta(t)$, thus constructing the time-variant model $W_y(t)$ of section modulus.

According to the experiment on some type steel samples, with the theme "indoor total immersion can speed up seawater corrosion for different periods", it can be seen that edge strip thickness of the section can decrease with time, as shown in the following TABLE I:

TABLE I. VARIATION IN THICKNESS FOR "INDOOR TOTAL IMMERSION CAN SPEED UP SEAWATER CORROSION FOR DIFFERENT PERIODS" OF SOME TYPE STEEL

Test duration/day	Thickness δ / mm			
	Test piece 1	*Test piece 2*	*Test piece 3*	*average*
0	3.270	3.100	3.120	3.163
1 week	3.110	3.090	3.050	3.083
2 weeks	3.070	2.960	2.940	2.990
4 weeks	2.970	2.940	2.760	2.890

Conduct regression analysis on the above experiment, and it can be known that dynamics degenerative process of some type steel section thickness follows the exponential function regression, which is the time-variant function

$$\delta(t) = \delta_0(1 - 0.026t^{0.42}) \tag{13}$$

In the equation, δ_0 refers to the initial thickness of the section.

Construct the I-shaped section modulus time-variant model

$$W_y(t) = \frac{(B^3 - b^3)\delta(t) + Hb^3}{12} / (B/2) \tag{14}$$

4.2 Bending strength time-variant model

I-shaped beam is mainly bearing the bending moment, which would generate the axial direction bending positive stress $\sigma = \frac{M \bullet y}{I}$, in which M is the loading bending moment, y refers to the distance between the expected point with the neutral axis, and I is the inertia moment. The most dangerous bending positive stress $\sigma_{max} = \frac{M_{max} \bullet y_{max}}{I}$, and $W = \frac{I}{y_{max}}$, in which y_{max} is the maximum distance between the upper point of the section and the neutral axis, and W is the section modulus in bending. In reality, the middle beam is only bearing the loading on the vertical direction, with $\sigma_y = \frac{M_{max}}{W_y}$ taken into consideration.

Based on the features of seawater corrosion, plane grillage structure can be affected by the corrosion of the ocean environment, while material properties can change with time. According to the "indoor total immersion can speed up seawater corrosion for different periods" of some type steel, it can be seen that the structure bending strength can decrease with time, as shown in TABLE II.

TABLE II BENDING STRENGTH CHANGE FOR "INDOOR TOTAL IMMERSION CAN SPEED UP SEAWATER CORROSION FOR DIFFERENT PERIODS" OF SOME TYPE STEEL

Test duration/day	Bending strength δ_y / Mpa			
	Test piece 1	*Test piece 2*	*Test piece 3*	*average*
0	786.291	762.859	769.302	774.815
1 week	775.858	771.921	761.143	761.073
2 weeks	774.105	745.218	720.511	758.537
4 weeks	763.007	638.059	573.451	655.703

Through regression analysis on the above experiment data, it can be known that the dynamics regression process of bending strength for some type steel follows the exponential function regression, which is the time-variant function.

Construct the time-variant model of bending strength:

$$\sigma_y(t) = \sigma_0(1 - 0.003t^{0.68}) \tag{15}$$

In the equation, σ_0 is the initial bending strength of the component.

4.3 Time-variant reliability calculation

3) Limit state performance function

Based on the previous analysis, the minimum life section of grillage structure dangerous section can be figured out, which serves as the criterion for time-variant reliability analysis. Moreover, maximum bending moment M_{max} can be solved by equation (9). Due to that section modulus $W_y(t)$ and bending strength $\sigma_y(t)$ are random time-variant models; limit state performance function of ship grillage structure can be set as:

$$G(t) = \sigma_y(t)W_y(t) - M_{max} \quad (16)$$

In the equation, σ_y refers to the bending stress of I-shaped section following the y-axis (unit: Mpa), $W_y(t)$ means time-variant section modulus of the grillage（unit: mm^3）, M_{max} refers to the maximum bending moment of the grillage（unit: $N \bullet mm$）。

In solving the Maximum bending moment M_{max} , it is assumed that ships are bearing no loads, namely having no influence from the cargo pressure. Moreover, external load M is only still water bending moment and wave bending moment, while external load of uniform distribution $q = \mathrm{M}/al$, calculated expression of which can be shown as follows:

$$q_{max} = \frac{M_s + \mu_w M_w}{al} \quad (17)$$

In the equation, q_{max} refers to the maximum external load of uniform distribution borne by the ship grillage, in which μ_w refers to loading reduction coefficient, M_s means the maximum still water bending moment（unit $N \bullet mm$）within T, M_w is the maximum wave bending moment（unit $N \bullet mm$）within T, a refers to the distance between main beams （unit mm）,and l is the length of main beam（unit mm）.

4) Time-variant reliability calculation

Performance function $G(t)$ is a random process, for which using the traditional FOSM method cannot calculate the consecutive time-variant reliability index. Therefore, out-crossing rate method is adopted in the paper, while reliability calculation is conducted with FOSM method. According to the literature [4], failure probability $P_{f,c}$ can be expressed with the following equation:

$$P_{f,c}(0,T) = P(\exists \tau \in [0,T], G(\tau) \le 0) \quad (18)$$

Boundary of time-variant Failure probability $P_{f,c}$

$$\max_{0 \le t \le T}[P_{f,i}(t)] \le P_{f,c}(0,T) \le P_{f,i}(0) + E[N^+(0,t)] \quad (19)$$

Here, $P_{f,i}(t)$ refers to the instant failure probability at t, and $E[N^+(0,t)] = \int_0^T \nu^+(t)dt$ means the average out-crossing time.

Definition of out-crossing rate is

$$\nu^+(t) = \lim_{\Delta\tau \to 0, \Delta\tau > 0} \frac{P(A \cap B)}{\Delta\tau}, \begin{cases} A = \{G(t) > 0\} \\ B = \{G(t+\Delta\tau) \le 0\} \end{cases} \quad (20)$$

Here, in case the value of time increase $\Delta\tau$ is small, finite difference method can be adopted to separate the equation, namely

$$\nu^+(\tau) = \frac{P\left(\{G(\tau) > 0\} \cap \{G(\tau+\Delta\tau) \le 0\}\right)}{\Delta\tau} \quad (21)$$

First, select a fixed τ & $\Delta\tau$, and performance function $G(t)$ would be two correlated random variables $G(\tau)$ and $G(\tau+\Delta\tau)$; FORM method is adopted to linearize performance function on their checking calculation points，with correlation coefficient $\rho_{GG} = \rho(G(\tau), G(\tau+\Delta\tau))$:

$$\rho_{GG}(t, t+\Delta\tau) = -\boldsymbol{\alpha}(t) \bullet \boldsymbol{\alpha}(t+\Delta\tau) \quad (22)$$

Here, $\boldsymbol{\alpha}(t)$ and $\boldsymbol{\alpha}(t+\Delta\tau)$ are unit normal state vectors .

N_1 is used to indicate the event $G(\tau) > 0$, N_2 is to indicate $G(\tau+\Delta\tau) \le 0$, and $P(N_1 \cap N_2)$, $\beta(t)$ & $\beta(t+\Delta\tau)$ are corresponding reliability indexes, and then

$$\begin{aligned} &P(G(\tau) > 0 \cap G(\tau+\Delta\tau) \le 0) \\ &= \Phi_2[\beta(\tau), -\beta(\tau+\Delta\tau), \rho_{GG}(\tau, \tau+\Delta\tau)] \end{aligned} \quad (23)$$

Out-crossing rate expression applied in failure probability is as follows:

$$\nu^+(\tau) = \frac{\Phi_2[\beta(\tau), -\beta(\tau+\Delta\tau), \rho_{GG}(\tau, \tau+\Delta\tau)]}{\Delta\tau} \quad (24)$$

In the equation, correlation ratio $\Phi_2(x)$ is two-dimensional standard normal function

Let $f_t = P(G(\tau) > 0 \cap G(\tau+\Delta\tau) \le 0)$, and the ultimate expression of out-crossing rate of failure probability is

$$v^{+}(t)=\lim_{\Delta\tau\to 0}\frac{f_t(\Delta\tau)-f_t(0)}{\Delta\tau}=\frac{df_t(\Delta\tau)}{d\Delta\tau}\Big|_{\Delta\tau=0}$$
$$=\left\|\vec{\alpha}'(t)\right\|\bullet\varphi(\beta(t))\bullet\Psi\left(\frac{\beta'(t)}{\left\|\vec{\alpha}'(t)\right\|}\right) \tag{25}$$

Here, $\Psi(x)=\varphi(x)-x\bullet\Phi(-x)$

Use equation(25) to solve the out-crossing rate $v^{+}(t)$, and figure out the boundary and reliability index value based on (19).

2 CASE STUDY

Some type ship of $103.2m\times 10.8m\times 3.19m$ is selected; the upper deck structure is 50×5 grillage, and I-shaped section material is usually constructional steel with normal strength, with the major parameters of grillage listed

TABLE III 50×5 GRILLAGE MAJOR PARAMETER

Para meter	L (m)	a (m)	B (mm)	H (mm)	b (mm)	δ_0 (mm)	E (Mpa)
Value	103.2	2	142	379	16.5	10.5	235

Based on equations (7), (8), (10) and (11), the stress of different nodes of the grillage can be shown

TABLE IV 50×5 GRILLAGE NODAL LOAD

Node	left end point	L/2	right end point
M_y / $N\bullet mm$	1.76×10^7	0.95×10^3	1.76×10^7
R / N	15.66×10^3	4.13×10^3	15.66×10^3

According to the result of TABLE IV, bending moment value of the ship of 50×5 grillage structure cross beam endpoint is 1.76×10^7 $N\bullet mm$ and bending moment value in the midpoint of the beam is $0.95\times 10^3 N\bullet mm$; through comparison, minimum life section of dangerous section shall be in the endpoint of the cross beam, while the point shall be seen as the criterion of time-variant reliability analysis.

Build the 50×5 grillage structure performance function as follows:

$$G(t)=\sigma_y(t)\bullet W(t)-1.76\times 10^7$$

In the equation, σ_y refers to the bending stress of I-shaped section following the y axis direction (unit: Mpa), $W_y(t)$ means time-variant section modulus of the grillage (unit mm^3) , and 1.76×10^7 refers to the maximum bending moment of the grillage (unit: $N\bullet mm$) 。

Based on the experiment with the theme “indoor total immersion can speed up seawater corrosion for different periods”, section modulus, bending strength and the corrosion rate are time-variant, but at each stage, the experimental data obey all normal distribution[4] [10]. Combined with the case of the preferred steel, the interpolation method was used to obtain the following distribution model and statistical parameters, and the variation coefficient was constant, with the distribution mode and parameter result shown in TABLE V:

TABLE V RANDOM VARIABLES AND PARAMETERS

Parameter	Distribution pattern	Mean Value	Variable coefficient
Edge strip thickness	Normal distribution	$10.5mm$	0.05
Bending stress	Normal distribution	$785MPa$	0.06
Corrosion rate	Normal distribution	$0.25\ mm / a$	0.1

As shown in Figure 2 , calculation has been conducted on the time-variant reliability and failure probability of ship grillage structure affected by the corrosion; in the initial period, the ship service is provided with high reliability, for which it is assumed that the failure probability when $t=0$ is 0. Figure 4and Figure 5 show the time-variant failure probability and time-variant reliability index change of grillage structure affected by corrosion.

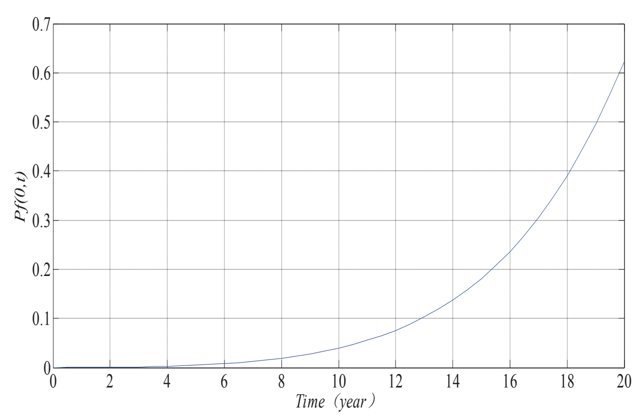


Figure 4. Time-variant failure probability of grillage structure affected by corrosion

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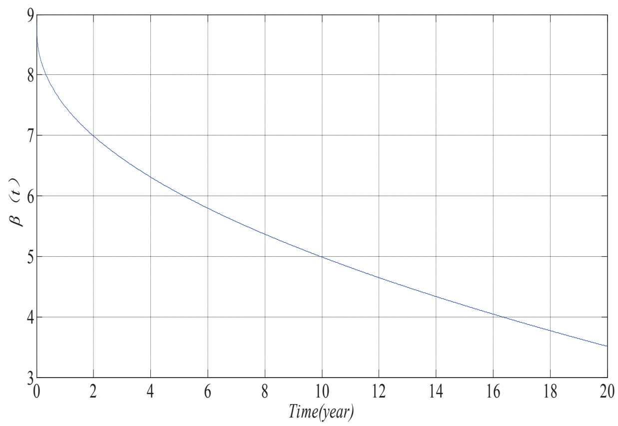

Figure 5. Time-variant reliability index of grillage structure affected by corrosion

Specific failure probability value (0~20years) of ship grillage structure affected by corrosion (every 5 years), as shown in TABLE VI.

TABLE VI CORROSION FAILURE PROBABILITY VALUE (0~20YEARS) OF SHIP GRILLAGE STRUCTURE AFFECTED BY CORROSION (EVERY 5 YEARS)

Time/ year	0	5	10	15	20
Failure probability P_{fc}	0	0.0046	0.0392	0.1811	0.6238

Conduct final analysis on the above calculation and results. From Figure 4 and 5, it can be seen that the failure rate of ship grillage structure increases with time change: in the initial period of the service (0), the failure probability is 0, and the failure probability increases slowly from 0~5 years with little change; the maximum structure failure probability is only 0.0046 due to little influence from the corrosion, thus causing less serious corrosion on section modulus; from5~15years, structure failure probability presents deflection increase compared with the previous years; from 15~20 years, structure failure probability has experienced sharp increase, and reached 0.6238 for the last year. Ocean corrosion's influence on grillage structure is accelerating, which could result in the obvious decrease of effective section modulus. Moreover, structure bending strength is obviously decreasing, thereby resulting in the increase of ship failure probability as well as reduction of reliability.

3 CONCLUSION

According to the ship structure and strength change under the corrosion environment, time-variant model of section modulus and bending strength is constructed. Moreover, out-crossing rate method and FOSM method are adopted to conduct calculation and analysis on the time-variant reliability of ship grillage structure under the corrosion effect.

1） Considering the time consecutiveness of the ship during the service process, pressure analysis is conducted on the corrosion. Moreover, pressure analysis is conducted on the grillage structure, thus finding the danger point of the structure for analysis. It can be seen that in the paper, minimum life section of dangerous section of ship grillage structure, at the end point of cross beam, can achieve a greater bending moment compared with other nodes, thus serving as the criterion for the reliability analysis. For this method, analysis is conducted on grillage strength, while the influence of corrosion environment on structure is also taken into consideration.

2） Take I-shaped section for example, and section modulus& bending stress under seawater corrosion are consecutive with time change; besides, time-variant model of section modulus and bending stress is constructed, while the reliability analysis method of grillage structure under the time-variant conditions is listed. Due to the use of out-crossing rate method and FORM method, time-variant reliability analysis on ship structure in the ocean environment could be more accurate, convenient and simpler.

3）It can be seen from the analysis that ships can gain high reliability in its initial service period. Due to the increase of the corrosion influence on the failure probability year by year, 15years ago, the failure probability changes little, while 15 years after, the failure probability has experienced great increase in the parabola mode, thus resulting in the obvious decrease of the reliability 20 years later.

In the paper, grillage unit used belongs to the upper deck plane grillage, which can also be used for other similar ship structures, and it could also be further expanded to more complicated plane grillage system for time-variant reliability analysis.

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