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Study on the preventive maintenance of the cabin structure based on the markov chain

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Abstract: *In view of the complex structure and the different damage situations of the cabin, the Markov state transition model was established considering the crack propagation at the damaged sites. The state transition probability matrix of related crack propagation was constructed using the equation of linear elastic facture mechanics to simulate the deterioration process of the main structural parts during navigation. Secondly, the maintenance matrix was added to the state transition model, and the distribution probability of the system state was predicted by the periodicity of Markov chain, formulating a reasonable maintenance strategy. Finally, the practicability of the preventive maintenance strategy was verified taking the marine oil FPSO 116 as the example. The maintenance plan formulated according to the calculation results could reduce the damage of the hull theoretically, preventing the occurrence of unexpected deterioration states, prolonging the service life of the hull, and providing a strategic reference for the formulation of the maintenance plans of the hull.*

Keywords: *Markov Chain, Preventive Maintenance, Crack Propagation, Marine Oil FPSO116*

1. Introduction

For the hulls on the sea, the maintenance is a essential activity. The damage induced by the propagation of fatigue cracks to the hull increases with the increasing service time, resulting in more serious degree of deterioration. The daily maintenance is essential to slow down the deterioration rate effectively and prevent the rapid propagation of hull cracks. However, relatively high operating costs were produced by the maintenance with high frequency. How to determine the appropriate maintenance frequency is difficult to be solved for most operators. Thus, the preventive maintenance, especially how to restrict the propagation of damages induced by the propagation of cracks, has attracted more attention in the academia.

A new method for the estimation of the growth rate of cracks has been applied since the landmark Paris formula was proposed in 1963[1]. There are more than 100 prediction models of the growth of fatigue cracks have been developed based on the Paris formula. Jianping Zhao et al. improved the accuracy of the fatigue life under the non-constant amplitude and simplified the calculation process through the combining the calculation method of Cycle by Cycle on the basis of the concept of the equivalent load in Paris formula[2]. Xiaohong Shi et al. verified the correctness and universality of the newly obtained formula, the accessibility of the parameters and the clarity of the physical meaning of the formula through analyzing and comparing three commonly used formulas and one newly obtained formula, predicting the growth rate of fatigue cracks of different materials [3]. Xiaoping Huang et al. believed that the prediction of fatigue cracks under the complex loads only needs to correspond to the material constant of the growth rate of cracks at R=0, which could solve the problem of the material constant of the growth rate of cracks under the complex loads[4]. Mohamed et al. reported that the fatigue cracks would appear in different positions of ship structures, and may occur in the early stage of the service life of ships. They proposed a probabilistic method for inspecting, monitoring, maintaining and optimizing the details of ships under the influence of fatigue to prevent the sudden failure of the damaged structural components and the associated consequences produced[5]. Haoyang Gu et al. corrected the growth rate of cracks on account of the length of the small cracks in the plastic area at the tip of cracks in the growth stage of the small cracks. They predicted the growth rate of cracks and the life of the research objects using the corrected model[6]. Hongbao Ruan et al. systematically calculated the stress intensity factor of the surface cracks at the longitudinal end node of the tank using the finite element software, and predicted the fatigue life of the end of the tank based on the fatigue growth method of fracture mechanics [7]. Du et al. proposed to predict the issue of crack growth in the engineering by combing the long-term and short-term memory with the Markov model after they realized that the stochastic characteristic of the variability of the fatigue crack growth was essential for maintaining the reliability and safety of structures [10]. Most of the above references studied the service life of different parts of the hull via various ways without further presenting the maintaining approaches which were necessary for the extension of service life based on the estimated life [8-9].

The research on the optimization decision of the maintenance mode of ships mainly takes the degree of corrosion or fatigue degradation of the research objects into account, promoting the reasonable maintenance strategy. Don et al. proposed a probabilistic optimization method to optimize multi-objectives aimed at the aging situation and the various uncertainties of the structure of ships, achieving the optimized repair plan for the structure [11]. Gong et al. obtained the probability distribution of the life cycle costs applying the Monte Carlo simulation method, determining the optimal inspection intervals of the dock repair of the hull [12]. Garbatov et al. developed a framework based on the risk, and performed the accounting of the structural design for the maintenance plan[13]. Wang et al. proposed a optimal maintenance strategy for the ship operators from the perspective of economy and environment [14]. Given the difficulty to conform the repairing degree, Duan et al. described the deterioration process of the ship pump applying the non-uniform gamma process, and proposed a maintenance strategy with the random maintenance quality[15]. Cullum et al. presented that the maintenance plan of ships should be continuously improved, and proposed a probabilistic method based on state monitoring data combined with the decision theory. The risk assessment and the elements of the maintenance schedule in the scheduling framework of RBM were analyzed using this method[16].

Given all those, it is necessary to perform the different maintenance for the equipment components in different positions and conditions when the hull is maintained daily, especially when the types of the equipment are complex and the running state of most equipment and components cannot be sensed in real time[17-18]. Although the Markov chain has been applied to many types of engineering activities, there is still no relevant references reported on the application of this statistical model to plan and optimize the maintenance of the hull structure. This work proposed a method to arrange the preventive maintenance for the hull structure using the Markov chain, optimizing the cycle of the daily maintenance of the hull [19-20].

2. Markov Model Without Considering the Maintenance

Markov model described the process of the research object transforming from one state to another, as presented in the Formula (1). This work described the deterioration of the damaged components using the Markov chain developed with six states. Figure 1 described the gradually deterioration of the state without the external interference for the structural components, i.e., from π_1 to π_6.

$$\pi_n = r \times Q^n \tag{1}$$

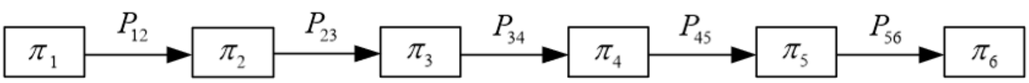


Figure 1: Markov chain model without considering the maintenance cracks

Where Q represented the state transition matrix, R was the initial state. The method of fracture mechanics was applied to predict the growth of cracks accurately, achieving the state transition matrix Q. The single curve model of the growth of structural fatigue cracks based on the variable amplitude load was expressed as:

$$\frac{da}{dN} = C\left[\left(\Delta k_{eqo}\right)^m - \left(\Delta k_{tho}\right)^m\right] \tag{2}$$

Where Δk_{eqo} and Δk_{tho} were the equivalent stress intensity factor range and the threshold value of the stress intensity factor range when the stress ratio R=0, respectively. C was the Paris coefficient. m was the index of the growth of cracks. However, for most structural steels, the Formula (2) could be simplified to the Formula (3):

$$\frac{da}{dN} = 1.414 * 10^{-8}[(\Delta\bar{\sigma})^{2.88} - (5.4)^{2.88}] \tag{3}$$

where a was the depth of the growth of cracks. N was the stress-number of cycles. $\Delta\bar{\sigma}$ was the stress amplitude. To determine the fatigue load spectrum accurately, the stress amplitude of the fatigue load was assumed to have the Weibull distribution of two parameters, and its probability function was shown in the Formula (4). Meanwhile, the spectrum of loads with variable amplitudes was transformed into the applying the equivalent stress method. The equivalent stress of the spectrum of loads with a constant amplitude was shown in the Formula (5). σ_i and n_i were the stress (maximum stress, minimum stress or stress amplitude) and cycle times corresponded to the load level i in the typical load spectrum. When α =2, the equivalent stress was the commonly used root-mean-square stress.

$$f(\Delta\sigma) = \frac{h}{q}(\frac{\Delta\sigma}{q})^{h-1} \exp\left[-\left(\frac{\Delta\sigma}{q}\right)^{h}\right] \qquad (0 \le \Delta\sigma < +\infty) \tag{4}$$

$$\Delta\bar{\sigma} = [\frac{\sum \sigma_i^{\alpha} n_i}{\sum n_i}]^{1/\alpha} \tag{5}$$

As the damage of the hull structure was mainly exhibited via the appearance and growth of the fatigue cracks, the main evaluation index was expressed using the growth of cracks when Table 1 was taken as the observation index of the research object.

The growth of cracks was divided into the states of E_i ($1 \le i \le 6$) by the step length Δa of cracks. Then the depth of cracks at different times and depths could be defined as follows:

$$a_u = a_0 + (j-1)\Delta a \tag{6}$$

Where a_u was the depth of cracks at different stages, Δa was the step length of cracks at different stages, and a_0 was the initial depth of cracks. The value of a_u could be obtained through the formula of the growth of cracks mentioned above, then the states E_i ($1 \le i \le 6$) of the research object could be roughly calculated according to the evaluation table of the crack state. In general, the final depth of cracks was the thickness of the structure. The thickness of the research target was the thickness of the cabin board as concerned as this paper. The Formula (3) could be redefined as follows:

$$\frac{\Delta a}{\Delta N} = 1.414 * 10^{-8}[(\Delta\bar{\sigma})^{2.88} - (5.4)^{2.88}] \tag{7}$$

ΔN in the Formula 7 corresponded to the stress cycle times of Δa in the state of the crack depth a_i. The process of Markov chain was the process of the state transition. The transition probability from the state i to the state j was expressed using P_{ij} which was also the component of the transfer matrix Q. Combining with the degradation degree of cracks in the Formula (6) and Table 1, the transfer matrix Q was:

$$Q = \begin{bmatrix} P_{11} & P_{12} & P_{13} & \cdots & \cdots & P_{1i} \\ 0 & P_{22} & P_{23} & P_{24} & 0 & P_{2i} \\ 0 & 0 & P_{33} & P_{34} & P_{35} & P_{3i} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & P_{ii} \end{bmatrix} \tag{8}$$

The purpose of using Markov method was to obtain the probability of various states of the system in a period, estimating the security and stability of the system. The system either maintained its current state, or gradually transited to the following stage after the system ran. The Markov method applied in this work included the following processes: 1) the Markov chain was divided into 6 states to represent the scale of the system degradation; 2) the probability of the system degradation corresponded to the probability of the state transition which was achieved according to the growth rate of cracks produced from the structural fatigue. These degradation probabilities constituted the transition matrix Q of the Markov chain. Finally, the probability of the system in each state was calculated using the property of the Markov stationary distribution.

The damage mentioned in this work mainly referred to the cracks produced by the fatigue in the component structure of the cabin during the navigation, and the structural instability produced from the continuous spread of cracks after the cracks appeared. The damage number was taken as the reference of the degradation degree of the state, and was divided into 6 grades as shown in Table 1. Among these grades, the grade 1 and 6 corresponded to the optimal and the most dangerous conditions respectively.

Table 1: The assessment table for the damage state

Degree	State	Damage number	Deterioration degree
1	Excellent	≤10	(0, 10%)
2	Good	10--30	(10%, 30%)
3	Fair	30--50	(30%, 50%)
4	Poor	50--70	(50%, 70%)
5	Bad	70--90	(70%, 90%)
6	Very bad	≥90	(90%, 100%)

The above table shows that the hull structure was extremely dangerous when the damaged components exceeded 90 for a single cabin. Proper maintenance and repair were crucial to prevent the hull structure being in a dangerous state.

3. Markov Model Considering The Maintenance

Appropriate maintenance and repair arrangements should be taken in time to alleviate the natural deterioration and propagation of cracks. The repair results achieved by the maintenance approach applied in various stages were also different, i.e., the best state π_1 could be restored by every maintenance. To ensure the application of the optimal maintenance strategy, the repair should also be in the form of the matrix. The worst state allowed in this work was assumed as π_4 when the safety of the hull navigation was guaranteed. The Markov process could be expressed by the Formula (9), and m represented the corresponding maintenance strategy[22].

$$\pi_n = r \times (M \times Q)^n \tag{9}$$

It is assumed that the maintenance was performed shortly after the overhaul, the maintenance of the damaged components would not induce the change of the whole states, and the repair in time would maintain the stability of the whole structure. The cabin was applied as the research object in this work. The degradation of the hull would reach π_6 to ensure the safety of the hull and the crew. Therefore, the emphasis of the maintenance was that the checked state could reach i. However once the i was reached, the corresponding repair strategy would be carried out to achieve the ideal repair state j.

Based on the irreversibility of the growth of cracks, the transition probability from the current state to any state in future was independent on how the current state was achieved. The growth process of cracks was a one-step jumping process, i.e., the crack in a state of i either kept staying in the state of j or jumped to the next crack $j+1$ with a longer length[23]. As the state transition matrix Q shown in Figure 1, the probability of transiting among the states or keeping stay in the same state was transformed into a form of matrix presented as follows:

$$Q = \begin{bmatrix} P_{11} & P_{12} & 0 & 0 & 0 & 0 \\ 0 & P_{22} & P_{23} & 0 & 0 & 0 \\ 0 & 0 & P_{33} & P_{34} & 0 & 0 \\ 0 & 0 & 0 & P_{44} & P_{45} & 0 \\ 0 & 0 & 0 & 0 & P_{55} & P_{56} \\ 0 & 0 & 0 & 0 & 0 & P_{66} \end{bmatrix}$$

The confirmation of the detailed value of P_{ij} referred to the calculation mode proposed in the reference of M.ASCE[24]. P_{ij} was the probability of keeping the original state of cracks, and $P_{i(j+1)}$ was the probability of entering the next state. Combined with the Formula (7), the property was shown as follows:

$$P_{i(j+1)} = \frac{1.414*10^{-8}\left[(\Delta\bar{\sigma})^{2.88}-(5.4)^{2.88}\right]}{\Delta a} \tag{10}$$

$$P_{i(j+1)} + P_{ij} = 1 \tag{11}$$

The work considered 5 corresponding maintenance strategies regarding this state transition as shown in Table 2. The first initial level was 1 and 2. The state returned to the state 2 after the highest deterioration degree reached the level 4. The second initial level was level 3. The maintenance returned to the state 1 after the highest deterioration degree reached the level 4. Finally, given the initial state already arrived the highest deterioration state 4, the system recovered to the state 3 after the maintenance. The various maintenance modes in Table 2 were transformed to be the expressions of matrixes as shown in Table 3. Meanwhile, it was also presented that there were some differences in the distribution probability of each state after carrying out various maintenance modes.

Table 2: Five maintenance strategies

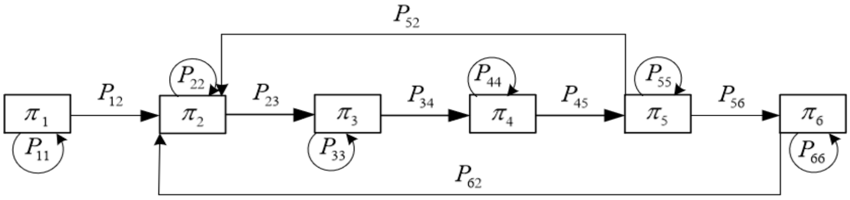
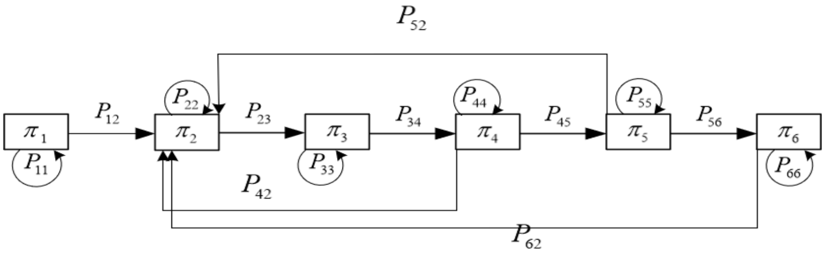
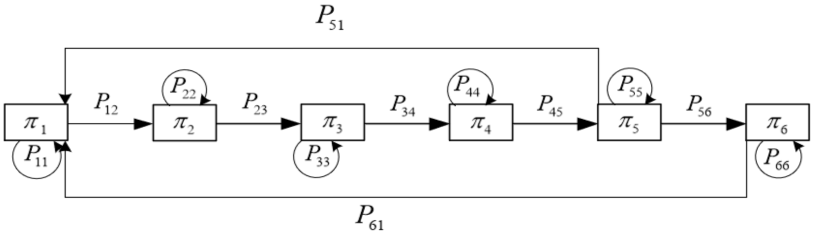
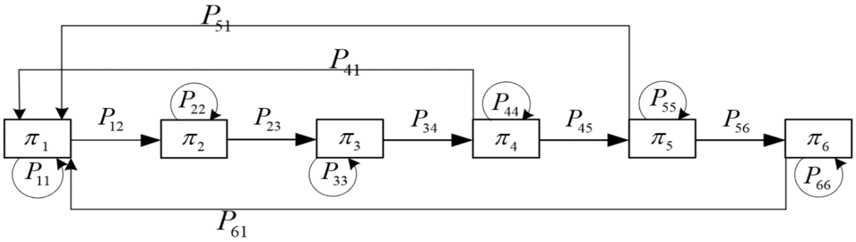
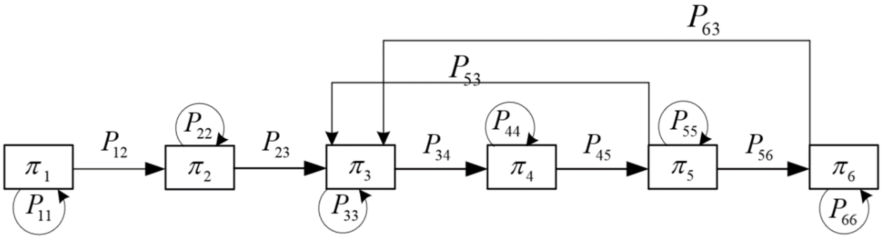
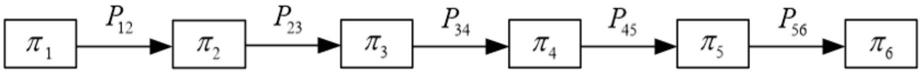
Number	Maintenance mode
1	
2	
3	
4	
5	
6	

Table 3: Maintenance matrix and the results

	Maintenance matrix	Results
1	$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$	[0 0.40950495 0.32673267 0.23762376 0.23076146 0.026138614 0]
2	$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$	[0. 0.53714286 0.42857143 0.03428571 0 0]
3	$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	[0.379401198 0.26347305 0.19760479 0.14371257 0.015808383 0]
4	$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	[0.443076923 0.30769231 0.23076923 0.01846154 0 0]
5	$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$	[0 0 0.53263158 0.42105263 0.046315789 0]
6	\	[0 01687032 0.02963089 0.03899935 0.0400121 0.03669417 0.83779317]

4. Application

4.1 Sample Data

The marine oil 116 FPSO was applied as the research object in this study. The maintenance and repair scheme was proposed according to the data of the structure condition assessment plan (CAP) for the hull structure performed in 2017, confirming that the hull structure was kept a relatively stable state before the docking repair in 2022.

The main dimension of the marine oil 116 FPSO were: 232m in length, 46 m in width, 16m in depth. As for the selection of the shape parameter h and the scale parameter q in the Formula (12) and Formula (14), the method applied in the reference reported by Ding Zhang[21] was referred combined with the empirical formula and design wave method to solve the parameters, where L was the length of the cabin, D was the molding depth, d_1 was the draft under the calculated working condition, and z

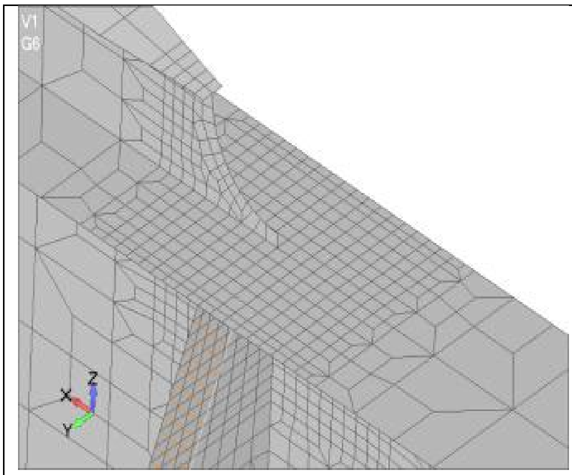
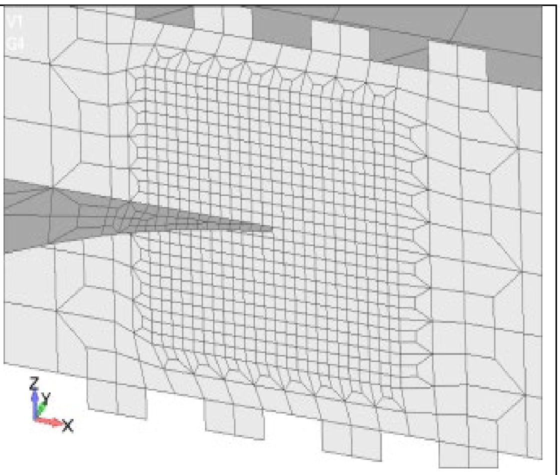
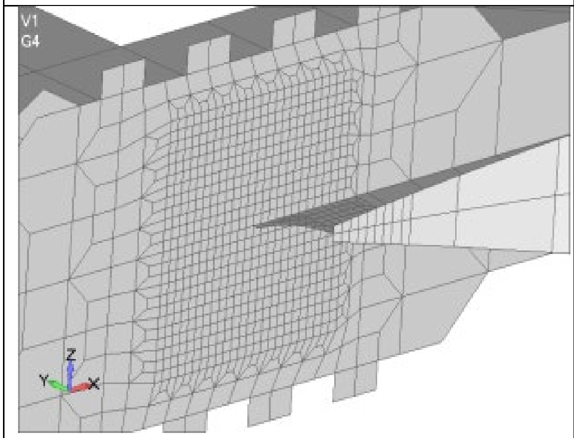
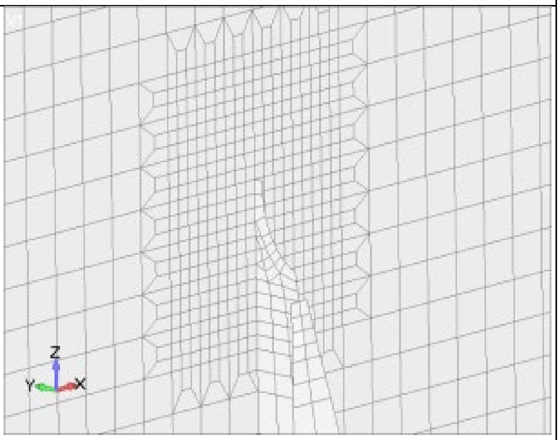
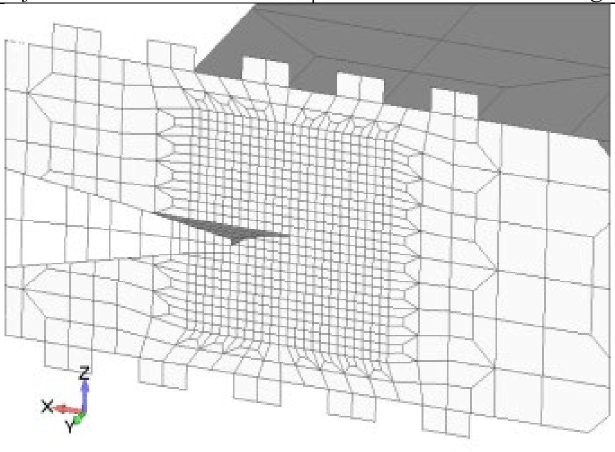
was height from the calculated point to the baseline. The calculated node positions and the structural conditions of each damaged component selected in this study were shown in Figure 3 and Table 4:

$$h = 1.45 - 0.036f\sqrt{L} \tag{12}$$

$$f = \begin{cases} 1 - 0.08\frac{z}{d_1} & (z \le d_1) \\ 0.92 + 0.08\frac{z-d_1}{D-d_1} & (z > d_1) \end{cases} \tag{13}$$

$$q = \frac{\Delta\sigma}{(ln(n_0))^{1/h}} \tag{14}$$

Table 4: Detailed diagram of the calculated node damage

 *Deck*	 *Transverse bulkhead*
 *Strong frame of the side cabin*	 *Side longitudinal*
 *Longitudinal bone of the longitudinal bulkhead*	

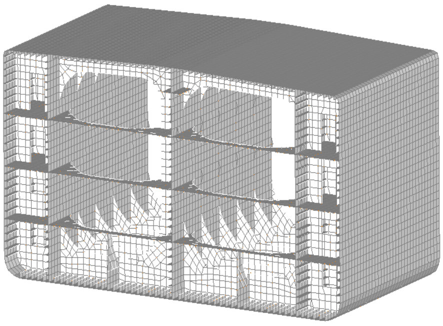


Figure 2: Target cabin

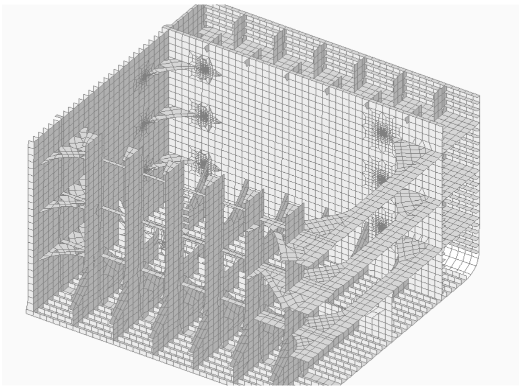


Figure 3: Damage effect

Table 5: Parameters of the node at damaged points

	Deck	Transverse bulkhead	Strong frame of the side cabin	Side longitudinal	Longitudinal bone of the longitudinal bulkhead
z_1	24.1	17.3	17.3	17.3	11.7
f	1	0.653	0.969	0.653	0.942
$\Delta\bar{\sigma}$	63.72	70.56	106.74	153.81	118.35
q	5.406	9.202	9.554	12.797	10.872
h	0.90	1.09	0.92	1.09	0.93

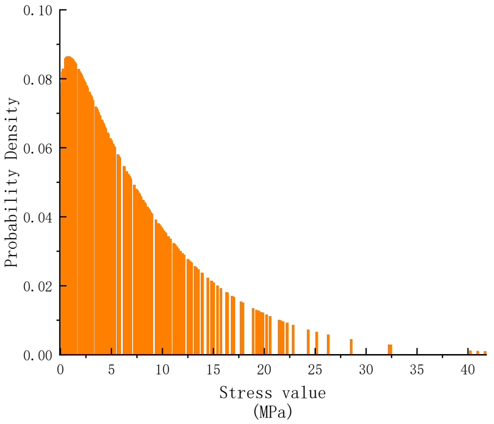


Figure 4: Stress range distribution of the wave-induced load

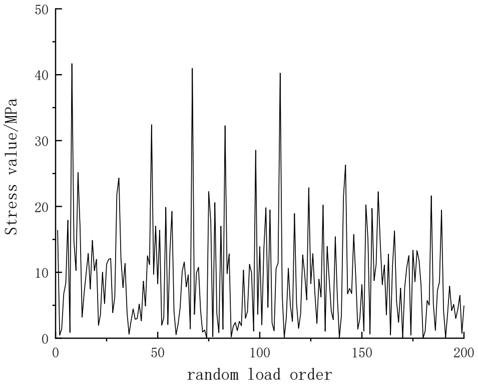


Figure 5: Probability distribution diagram of the wave-induced load stress range

Two parameters of the Weibull distribution were calculated according to the method presented above: the shape parameter *h* was 0.917 and the scale parameter *q* was 15.1039, and the stress range

$\Delta\sigma$ induced by the wave loads of the target ship was calculated using the Formula (8). 10^6 of the random numbers generated by the matlab were applied as the random stress amplitudes. Each random number was applied as the wave-induced stress range, generating the load probability density histogram (Figure 4) and the sequences of the random stress range (Figure 5). The state transition matrix Q was finally determined according the growth rate if the cracks (Figure 6).

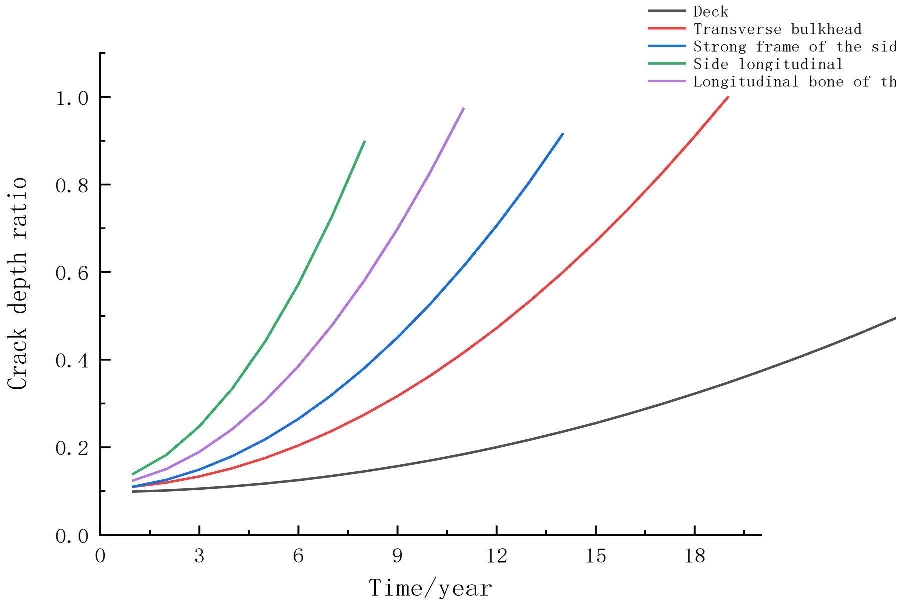


Figure 6: Growth rate of cracks

$$Q=\begin{bmatrix} 0.96 & 0.04 & 0 & 0 & 0 & 0 \\ 0 & 0.94 & 0.06 & 0 & 0 & 0 \\ 0 & 0 & 0.92 & 0.08 & 0 & 0 \\ 0 & 0 & 0 & 0.89 & 0.11 & 0 \\ 0 & 0 & 0 & 0 & 0.85 & 0.15 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

4.2 Maintenance Optimization

The processes of the maintenance strategies were similar and their difference was just the maintenance methods. Thus, the strategy 2 was taken as the example, and its maintenance matrix was as follows:

$$M=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

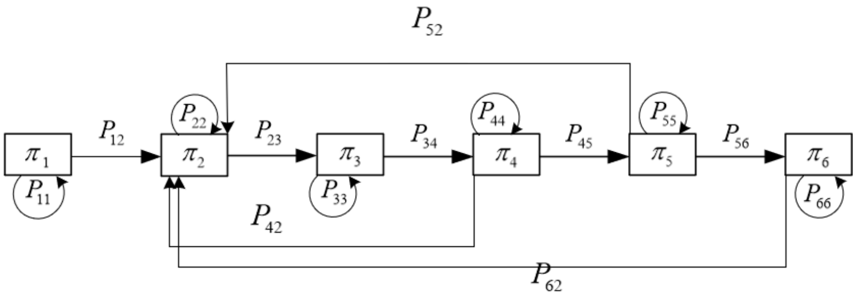


Figure 7: The model diagram of the maintenance policy

The suggested maintenance strategy was applied to the research object, i.e., the state of the system would never be higher than 4. The system always returned to the state 2 after the maintenance. The rule sequence of the states 2, 3 and 4 were created as shown in Figure 7:

Markov chain was a description of the stationary distribution process. The system was in a stable state especially when *n* approached the infinity, i.e., the system would be achieve an equilibrium state after the numerous transformations no matter what the initial state was. If this equilibrium state existed, it must be unique and meet the following conditions:

$$\pi(i) \geq 0, i \in S \tag{15}$$

$$\sum \pi(i) = 1 \tag{16}$$

$$\pi(j) = \pi(i) \times Q(i,j) \tag{17}$$

The maintenance strategy was achieved in the form of matrix, and the Formula (17) was transformed to be the Formula (18)

$$\pi(j) = P(i) \times [M(i,j) \times Q(i,j)] \tag{18}$$

where each component if the vector π(j) corresponded to the time remained in the state j when the system reached the periodic behavior. Thus, the observed state vectors for 20, 40 and 80 times for the analysis of the maintenance strategy were as follows:

$$\pi_{20} = [0.44200243 \ \ 0.36613541 \ \ 0.19186216 \ 0 \ 0]$$

$$\pi_{40} = [0.19536615 \ \ 0.50662 \ \ 0.29801385 \ 0 \ 0 \ 0]$$

$$\pi_{80} = [0.03816793 \ 0.59417934 \ \ 0.36765273 \ 0 \ 0 \ 0]$$

It could be found from the above results that the more iteration times, the greater the probability of the system being in the state of 2 and 3. The probability of the system being in the state 1 decreased from the initial 40.2% to 16.54% and 3.82%. Finally, when j approached the infinity, the result was as follows:

$$\pi = [0 \ \ 0.53714286 \ 0.42857143 \ 0.03428571 \ 0 \ 0]$$

The other four results were also shown in Table 2. The state 6 was the result without the manual maintenance.

$$\pi_6 = [0.01687032 \ 0.02222317 \ 0.02853237 \ 0.02896191 \ 0.02694658 \ 0.87646566]$$

It was found by comparing the final results that the probability of the system being in the state 6 was 87.6% without taking the maintenance. The system was in a changeable state after taking various maintenance measures, i.e., the state of the maintained system would be in the state 1 or 2 with a high probability when applying the strategy 1 or 2. The state of the system being in the first stage was extremely high when applying the strategy 3 or 4. The system only returned to the medium state 3 or 4 mostly even after the proper manual maintenance when applying the strategy 5 (i.e., in the case of a relatively poor state).

Given all these, there was no specific priority sequence for the selection of the five maintenance strategies without considering the strategy 5. The more comprehensive maintenance plan should be formulated combing with the fatigue damage of each component of FPSO116. This comprehensive plan could be divided into two situations roughly: the maintenance strategy 2 was preferred for the components in relatively poor state, and the strategy 4 would be a better choice for the components in the normal or better conditions.

4.3 Maintenance Strategy

The maintenance strategy of the marine oil FPSO 116 was formulated combining the maintenance records with the development trend of the structural deterioration. The structural state of the maintenance area was determined comparing with the evaluation table of the damaged states in Table 1 according to the data in the thickness measurement report of the marine oil FPSO 116[27]. The results show that the damage at the side longitudinal bone was the most serious position with the relatively high degree of the structural deterioration. The deterioration degrees of the side cabin strong frame and the longitudinal bone of the longitudinal bulkhead were relatively slower. The probabilities of the damage on the deck and the transverse bulkhead were the lowest. It was assumed that the structure instability would be occur when the depth of cracks extended to the 1/3 of the plate thickness (Figure 6).

The optimized maintenance strategies were worked out according to the growth rate of cracks at various components and the selected maintenance mode, which were presented in Table 7.

Table 6: Record of the damage number

Deck	Transverse bulkhead	Strong frame of the side cabin	Side longitudinal	Longitudinal bone of the longitudinal bulkhead
12	17	54	126	76

Table 7: Maintenance frequency for various components

Components	Maintenance frequency (year/each time)	Maintenance strategy
Deck	3	Strategy 4
Transverse bulkhead	3	Strategy 4
Strong frame of the side cabin	2	Strategy 2
Side longitudinal	1	Strategy 2
Longitudinal bone of the longitudinal bulkhead	2	Strategy 2

5. Conclusions

The maintaining strategy of the cabin was investigated using the prediction model of Markov chain and verified in combination with examples in this study. The results showed that the damage degree of components more detailed applying the Markov theory to simulate the process of the structural deterioration. The maintaining strategy based on this could prevent the system from the unexpected deteriorating state and enhanced the safety of the hull structure. In addition, the maintaining strategy proposed in this study also effectively alleviated the workload of the crew in each maintenance operation compared with the traditional maintaining plan, providing the strategic reference for the formulation of other maintaining methods of the hull. However, the five schemes in this study were divided into two categories without comparing the economic benefits if the five maintaining schemes specifically in the combination of the actual maintaining costs. Therefore, considering the various damage conditions, the corresponding maintenance costs were calculated and compared combined with the specific maintenance methods and the effect after the maintenance for the next research plan, improving the model of the hull maintenance strategy.

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