Reliability Investigation of Aging Offshore Fixed Structure Using a Probabilistic Method

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Abstract. Indonesia has hundreds of offshore fixed structures, of which 54% have exceeded their design life. Therefore, it is necessary to investigate the structure's integrity so that it is safe to operate against all kinds of loading. One of the uncertainty factors is the weather which affects the wave height in the sea. In this study, the reliability analysis of the offshore fixed platforms was performed using a probabilistic method. The uncertainty parameter studied is the thickness of the corroded structural member against different wave heights. The uncertainty parameter values were obtained from the Monte Carlo simulation. Pushover analysis is performed using the incremental wave analysis (IWA) method to get the base shear value based on the uncertainty parameter. This research results in the base shear limit from the relationship between the probability of failure and the demand parameter as a function of the annual probability.

Keywords: Corrosion, Monte carlo, Offshore platform, Probability failure, Reserve strength ratio.

1 Introduction

Indonesia is an archipelago country where many oil and gas energy sources are exploited offshore using an offshore platform. This structure supports the offshore oil or gas drilling process in offshore. Indonesia has had offshore platforms since 1970, with 613 offshore structure platforms scattered throughout Indonesian waters based on SKK Migas data [1]. These platforms are widely used in Indonesia because they are suitable for application in the Indonesian sea with depths below 200 meters. Many structures of offshore platforms are built in Indonesian waters that have aged. Currently, the petroleum industry is experiencing a downturn due to the relatively low value of petroleum, so many sectors carry out optimization costs for extending offshore platform service life. In general, the structure of offshore platforms is designed to have a design life of 20 years. In Indonesia, many offshore platforms operate beyond the design life since there are still oil or gas reserves in the operated area. Fig 1 shows the representation data of offshore platforms in Indonesia based on age with 613 offshore structure platforms [1].

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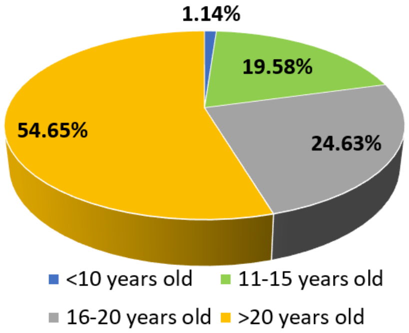

Fig 1. Offshore platform data in Indonesia [1].

Fig 1 shows that 54.65% of those offshore platforms have ages of more than 20 years, whereas these structures are designed to have a design life of 20 years. An example of the conditions of aging fixed offshore platforms in Indonesia is shown in **Fig 2** [2].

Fig 2. An example of the conditions of aging offshore platforms in Indonesia [2]

The reliability of the aging offshore platforms is questionable since the structures have deteriorated, which raises a concern for the oil and gas community to ensure that the aging offshore platforms can operate safely against uncertainty factors during operation. One of the uncertainty factors is the weather which affects the wave height in the sea. During the design phase, the offshore platforms were designed with new intact strength against the highest sea wave height at a specific return period. However, during operation, the old structures experienced a decrease in strength due to corrosion, and one of the design parameters, i.e., sea wave height, began to be difficult to predict in practice. Therefore, a study is needed to determine the reliability of these structures, given the circumstances.

This study aims to investigate an aging offshore platform in Indonesia using a probability method to obtain the Reserve Strength Ratio (RSR) value based on the probability function. The RSR value is a reference for the safety factor of the offshore platform. The probability of failure occurring in aging offshore platform structures is analyzed using probability methods and structural collapse analysis. Uncertainty parameters of the wave height are analyzed statistically to produce a probability value for structural failure. The corroded thickness value was obtained from random data using the Monte Carlo method.

2 Methodology

2.1 Multiple-stripe method

In order to measure the demand distribution for structural parameters, the first step is to carry out an incremental analysis of each structural model at various sea wave heights. The study measures the structure's response and probability to sea wave loading, with the base shear as the demand parameter. This method is known as multiple stripe analysis. Golafshani et al. [3,4] assessed the structure of offshore platforms with the probability method in the Persian Gulf under extreme ocean wave conditions. **Fig 3** shows the result of the multiple stripe analysis. The graph's points represent different structural responses (base shears) at the same wave height, resulting from other structural models.

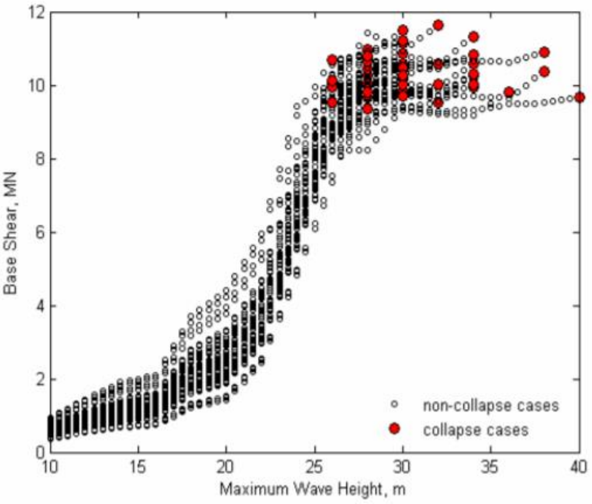

Fig 3. Multiple-stripe analysis [3,4]

2.2 Demand parameter hazard

The demand Hazard parameter precisely measures the structure's performance because it is related to the annual frequency of demand parameter events (DP)> x. By using the total probability theorem, the evaluation of DP hazard can be easily simplified by connecting the wave height hazard and multiple-stripe analysis using the maximum wave variable Hmax so that the hazard demand parameter (λ_{DP}) can be expanded by taking into account all possible wave heights (H).

$$\lambda_{DP}(x) = P[DP > x] \tag{1}$$

$$\lambda_{DP}(x) = \sum_{allh} P[DP > x|H_{max} = h].(P|\, H_{max} = h) \tag{2}$$

Where P [DP> x | Hmax = h] is the conditional probability of being exceeded by the demand parameter (base shear), at a given wave height (h), which the distribution of the demand parameter can directly estimate through multiple-stripe analysis. P|Hmax = h is the probability that the wave height will be equal to a specific value (h) which is obtained directly from the probability analysis of the maximum wave height. The above expression can be rewritten for continuous variables in the following form.

$$\lambda_{DP}(x) = \int_h P[DP > x | H_{max} = h].\left|\frac{d\lambda_{Hmax}}{dh}\right| dh \tag{3}$$

$$\lambda_{DP}(x) = \int_h G_{DP|Hmax}(x|h).\,|d\lambda_{Hmax}(h)| \tag{4}$$

Where G_ (DP | Hmax) (x | h) is the conditional complementary cumulative density function (CCDF) for each wave height (h), and λ_Hmax (h) is the wave height hazard for the specified wave height (h). G_ (DP | Hmax) (x | h) can be expanded based on the case of collapse (C) and non-collapse (NC) using total probability theory, as follows.

$$G_{DP|Hmax}(x|h) = G_{DP|Hmax,NC}(x|h).\,P_{NC|Hmax}(h) + G_{DP|Hmax,C}(x|h).\left(1 - P_{C|Hmax}(h)\right) \tag{5}$$

Where P_ (NC | Hmax) (h) and (1-P_ (C | Hmax) (h)) are the conditional probabilities of a non-collapse case at a given wave height,

2.3 Reserve strength ratio hazard

The Reserve Strength Ratio (RSR) is an indicator of structural resilience that is used extensively in assessing the structure of offshore platforms. RSR is obtained from the results of the base shear at the time of the collapsed structure (V_C) compared to the design base shear (V_D). The design base shear is usually the result of loads on the structure combined with environmental loads with a 100-year return period. In general, to calculate the current RSR value using the equation approach below,

$$\text{RSR} = \frac{V_C}{V_D} \tag{6}$$

V_C is the base shear that makes the structure collapse, and V_D is the base shear of the structure loading with the environmental load of a 100-year return period. The RSR value through a probabilistic approach, the V_C value is obtained from the base shear associated with the base shear hazard or the probability of the RSR hazard so that from this result, a graph of the RSR value with annual probability can be made.

3 Results and Discussion

3.1 Case Study

This study examines a four legs offshore structure built in 1974 and standing in 135 ft water depth. Corrosion problems were arised in some parts of the member, especially the splash zone, because the structure is aging. Corrosion is a variable of uncertainty used in this study. Limited access to measurements in the splash zone area makes measuring member thickness difficult. In this case, the thickness value of the structure subjected to corrosion is randomly used by the monte carlo method. **Figure 4** shows the structure of the analyzed offshore platform.

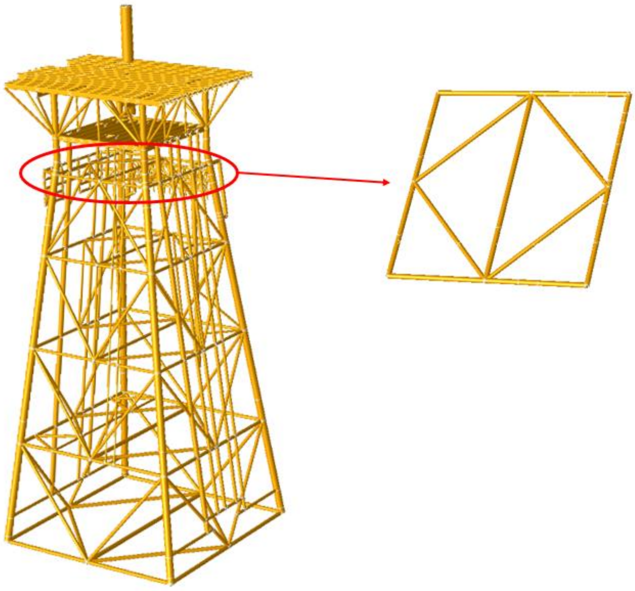

Fig 4. Corroded members

3.2 Wave Hazard Parameter

The annual maximum wave height data is used to determine the cumulative pattern of its distribution. **Figure 5** shows a comparison of several theoretical distribution approaches is carried out. In this case, two theoretical distributions are used: normal and log normal. The results of the comparison of the two theoretical distributions are as follows.

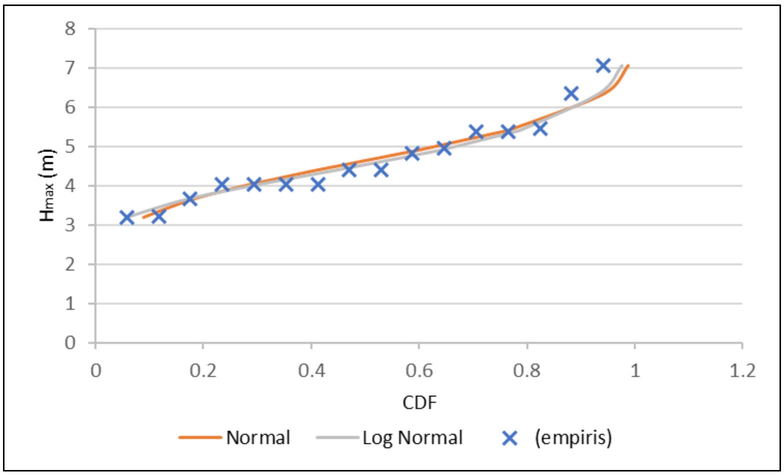

Fig 5. Graph of comparison between the theoretical and empirical distribution.

Based on **Figure 5**, it is known that the log-normal distribution has the most minor error value on the empirical distribution. These results are used as a reference for determining the probability of the wave hazard function, which will use the log-normal distribution approach. Wave heights are used to perform incremental wave analysis (IWA), ranging from 5 m to 17 m with intervals of 0.5 m. The wave height probability values used in the study are shown in table 1.

Table 1. Probability of wave height used in the analysis

H_{max} (m)	$P(H_{max})$	H_{max} (m)	$P(H_{max})$
5	0.3246	11.5	2.995E-05
5.5	0.2251	12	1.288E-05
6	0.1377	12.5	5.539E-06
6.5	0.0768	13	2.387E-06
7	0.0399	13.5	1.032E-06
7.5	0.0197	14	4.478E-07
8	0.0093	14.5	1.952E-07
8.5	4.282E-03	15	8.550E-08
9	1.925E-03	15.5	3.765E-08
9.5	8.514E-04	16	1.668E-08
10	3.722E-04	16.5	7.431E-09
10.5	1.614E-04	17	3.332E-09
11	6.962E-05		

3.3 RSR Calculation

This analysis uses a wave height of 5 m - 17 m with an interval of 0.5 m. A non-linear pushover analysis was performed for each wave height with a wave load factor 1.0 for each structural model. From pushover analysis, the base shear value is taken at the time before and during the collapse. Using equation 4, the demand parameter is calculated at each wave height and corrosion thickness, resulting in **Figure 6**.

To obtain the RSR value according to equation 6, it is necessary to calculate the collapse limit point in each case of corrosion thinning with respect to wave height. The probability of failure can be calculated using the following equation

$$\lambda_{LS} = \int_X F_C(x).\,|d\lambda_{DP}(x)| \tag{7}$$

Where λ_{LS} is the mean annual frequency of the collapse point limit requirement (frequency limit requirement), F_C is the conditional cumulative density function of the ultimate capacity for the collapse point limit requirement, also known as the fragile function and $d\lambda_{DP}$ is the differential of the hazard parameter demand. From the results of the above equation, the probability value of failure λ_{LS} is 8.5744E-06. If the limit state frequency value is related to the demand parameter (figure 6), the limit value of the base shear is 3.85 MN. The RSR is determined from equation 6 by comparing the limit state value and 100-year base shear occurrence. **Figure 7** shows the relation between RSR and annual exceedance probability.

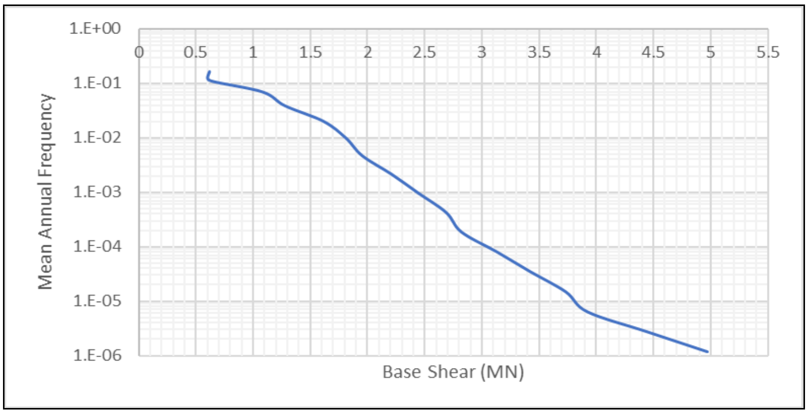

Fig 6. Mean annual probability analysis of demand parameters.

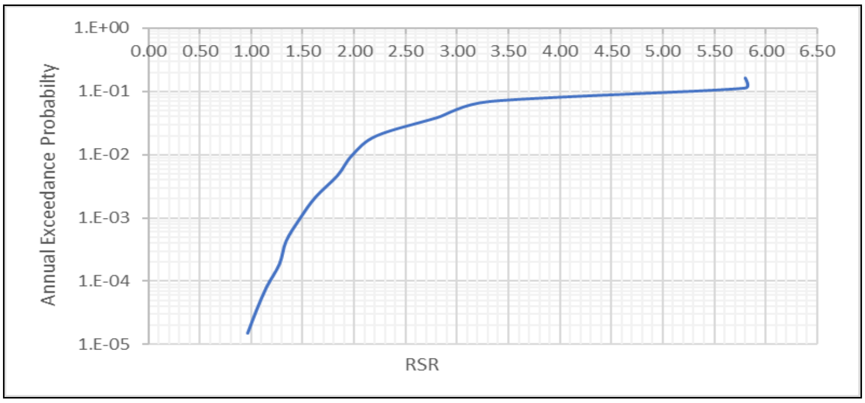

Fig 7. Annual exceedance probability of RSR

8 Conclusion

In this paper, an analysis of RSR is conducted using a probabilistic method that combines nonlinear incremental analysis and Monte Carlo simulation. By utilizing wave hazard represented by mean annual frequency and the uncertainty of corrosion-induced degradation in the splash zone area, the value of base shear is obtained based on the likelihood of its occurrence. By integrating the demand parameter curve with the distribution of jacket capacity (expressed as the base shear value), as acknowledged by the IWA, it becomes possible to assess both the annual probability of failure and the frequency of failures. The study concludes that the demand parameter curve's minimum value corresponds to the limit state's frequency. Notably, the probability of failure for this limit state is 8.5744E-06. Consequently, offshore platform structures subject to corrosion in this investigation are constrained to accommodating a maximum base shear value of 3.85 MN. The RSR can be determined from these limit values for each occurrence probability, facilitating industrial stakeholders in justifying the potential structural failures.

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