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Reliability Analysis of a Four-legged Jacket Offshore Platform: A Case Study

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Abstract. Offshore oil and gas exploration and exploitation requires reliable infrastructure. One crucial issue to consider is the reliability of the structure. Structural designs generally use deterministic or fixed values in their calculations. However, the factors involved in the design process may be random variables, such as environmental loads, materials, dimensions, and operational conditions, which may vary. Therefore, when calculating the reliability of a structure, these random variables must be treated with the science of statistics and probability. This research uses probabilistic and statistical methods via the Monte Carlo method to analyze the reliability of offshore jacket structures. The jacket platform is destined for the four-legged Java Sea around Gresik, Indonesia. The research results show that the Jacket platform has a high level of reliability for operating loads of K = 0.9883 and extreme loads of K = 0.9963 based on reliability analysis using the Monte Carlo Simulation method. Although the reliability figure does not exceed 1, this can be taken as a sign that the Jacket platform is declared safe in the analyzed situations. This reliability analysis ensures that the jacket platform is reliable and safe in dealing with the various environmental conditions and loads encountered during its operational life.

1. Introduction

Oil production offshore requires high technology. One type of offshore surfing platform is floating (semisubmersible) and fixed (jacket structure and gravity structure). In Indonesia's shallow waters, the commonly used platform is the fixed type, specifically the jacket structure. The platform uses a configured member and pile configuration to withstand loads of wind, current, and waves. Designing a jacket structure requires design criteria as a reference in designing the structure. The strength of the basic jacket structure on an offshore platform depends on the strength of the tube joints connecting the jacket legs and the retaining wire. Accuracy in calculating statically the strength of this tube connection has a very important meaning to ensure that the structure remains intact and functions properly during operation [1]. The American Petroleum Institute has issued regulations on the planning, designing, and constructing of a jacket platform called the API RP 2A – Working Stress Design (WSD) [2].

Design the jacket structure and find the initial structural configuration for the foundation jacket structure to maximize its structural rigidity. It can also provide sufficient resistance to extreme design loads and improve their dynamic performance [3]. In addition, it requires the ability to achieve the desired platform goals in operational and extreme conditions throughout its operating life, namely the reliability of the structure. The reliability of the jacket is measured by the reliability index and the probability of failure [4]. Deterministic analysis using a security factor approach is no longer sufficient consideration. Especially in offshore structures that face the irregular or random nature of the type of load. A probabilistic analysis must be presented to deal with this problem and provide the necessary information for optimal design [5].

Statistical uncertainty is indeed introduced in parameter estimates which are often involved in probabilistic models used for reliability analysis. When these parameters are not known with certainty, the probability of failure and the reliability index are also variables whose value cannot be ascertained [6].

The reliability assessment of the platform is conducted comprehensively, taking into account the deformation and energy of the jacket platform. Some of the random variables in this study include Young's modulus, the yield strength, the strain hardening rate; the diameter and thickness of members; the water depth; the wave height and period; the wave velocities on the surface, middle, and base of the platform; the drag coefficient; the inertial coefficient; and the horizontal concentrated scaled loads. It determines how performance functions are affected by these variables and identifies variables that are considered in platform reliability and performance analysis [7]. Wave height, current velocity, and wind speed are factors that influence the uncertainty of environmental loads in offshore platform design. Environmental load factors suitable for Indonesian waters are required to design structures that can withstand the specific conditions in those waters. That requires a structural reliability analysis. The reliability index indicates the probability that the criterion structure performance is met, known as structural reliability [8].

The basic concept of reliability analysis states that capacity and load factors, along with the assumptions used in the analysis, are statistical quantities with average values and standard deviations, and follow certain probability distributions such as normal, log-normal, or other probability distributions. Reliability is the opposite of the probability of failure. In reliability analysis, it is to evaluate the extent of this reliability to be able to understand how safe or reliable a structure or system is and, in many cases, to ensure that the risk of failure remains within acceptable limits [9].

Using a higher target reliability index might result in a greater degree of confidence in system security. However, this approach can also lead to heavier structures and result in unnecessarily higher costs. Therefore, adjustments were made to establish a reasonable target value of the reliability index sufficient to achieve the desired confidence level without sacrificing structural efficiency [10]. For a given configuration, member reliability, material, and loading statistics are designed standard deviation graphs that can be constructed for various structural index values of the model. For accurate and effective load estimation, stochastic procedures are based on reliability methods and Monte Carlo simulation (MCS) [11].

This research aims to evaluate the level of reliability in jacket structure design. The critical factor to consider is system reliability, essential in determining the optimal structural configuration. When the system being studied involves variables or parameters that have random values or experience random fluctuations, the simulation method is an appropriate choice. Through the application of Monte Carlo simulation methods, the reliability of structures can be assessed by considering uncertainties that may arise in variables or parameters during the design process. This approach helps find a more reliable and optimal solution to achieve the desired jacket structure.

2. Research Methods

The methodology used in this study is shown in the flowchart in **Figure 1**.

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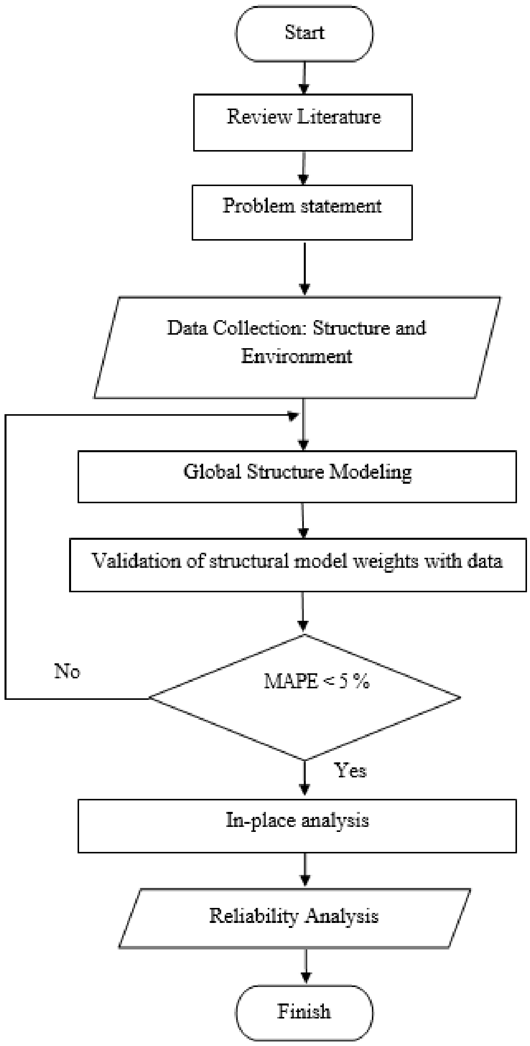

Figure 1. Research flowchart

In this research, modeling, and loading were carried out on the structure of the jacket platform operating in the Java Sea around Gresik, Indonesia which has four legs. The modeling was conducted using finite element method-based software and analyzed using the API RP 2A WSD code. In modeling consider environmental loads such as currents, waves, and wind. Structural inspection is carried out using inplace analysis which is validated according to the standards used.

In the next process, the examination of the results of the inplace analysis is a critical member. Reliability analysis will be carried out on this member to obtain reliability under the conditions of member stress performance in inplace analysis. Reliability analysis using the Monte Carlo simulation method is a powerful approach to determine the reliability of the structure. Through reliability analysis using the Monte Carlo simulation method, we can obtain more robust information about the reliability and performance of structures in various scenarios and load variations. This helps in identifying and mitigating potential problems or risks of failure, as well as designing safer and more reliable structures.

Structural data in this study are presented in **Table 1** below:

Table 1. Platform Structure Data

Description	Appurtenance
Structure Type	Wellhead Production
Location	East Java Sea
Number of Decks	4
Structure Elevation	Jacket Plan EL (-) 30 m
	Jacket Plan EL (-) 19 m
	Jacket Plan EL (-) 8 m
	Jacket Walkway EL (+) 4m
	Sub-Cellar Deck T.O.S EL (+) 9.5 m
	Cellar Deck T.O.S EL (+) 13.5 m
	Wellhead Access T.O.S EL (+) 16.9 m
	Main Deck T.O.S EL (+) 20.3 m
Leg Batter	No Batter
Platform Orientation	(+) 45°

3. Result and Discussion

3.1. Modeling of the jacket offshore platform

The jacket structure to be modeled is a platform operating in the Java Sea around Gresik, Indonesia with four legs and a water depth of about 30 m. The structure analyzed in this case will use the code, namely API RP 2A WSD. The location is at coordinates 6° 47' 50.470" S;112° 29' 18.783" E. This geometric modeling is the first step in analyzing the structure globally. In the jacket, the topside and jacket are modeled according to the existing data. The modeling results in this study can be seen in **Figure 2** below:

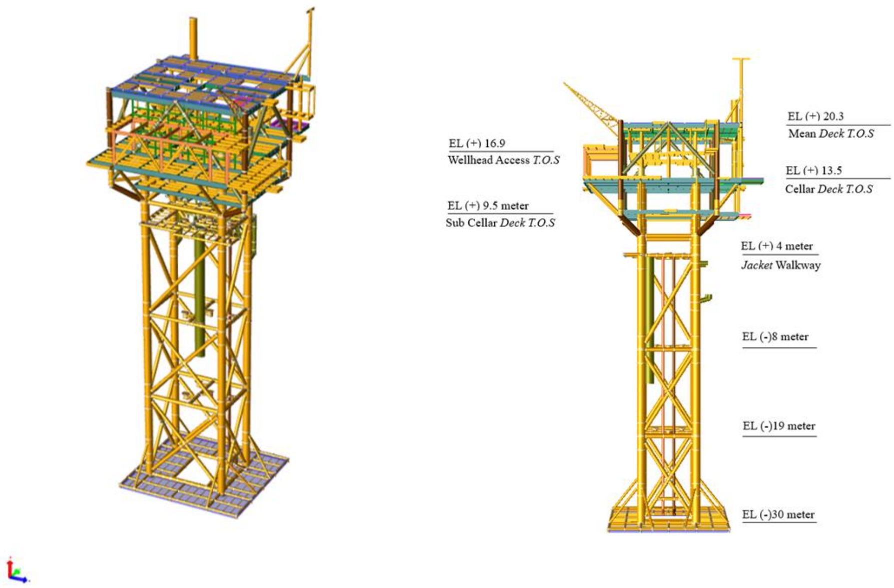

Figure 2. Modeling results for a four-legged platform jacket

3.2. Inplace Analysis

The results of in-place analysis of a structure are critical information that influences the design and operational safety of that structure. Using the unity check as a guide, the results of this analysis provide an overview of the extent to which stresses in the structure approach or exceed the allowable limits.

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Practically, if the unity check (UC) exceeds 1, this is an important warning that the structural component cannot safely support the load.

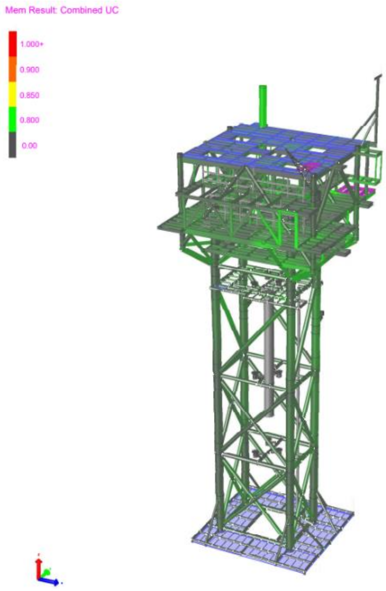

Figure 3. Inplace Analysis Results

By looking at Figure 3, which shows the results of in-place analysis, it can be concluded that no structural components have a unity check exceeding 1. Therefore, it can be concluded that the structure will not fail when operating under existing gravity loads and environmental loads. This analysis is an essential basis for ensuring the overall reliability and safety of the structure.

3.3. Reliability Analysis

Reliability analysis plays a central role in this research to evaluate the level of potential failure in the structure being studied. With an emphasis on failure patterns, this research focuses on specific parts of the structure that can potentially undergo full plasticity. Determining the failure or success of the part is based on the value of the reliability factor (MK). More specifically, some structures are categorized as "failed" if MK < 0 or MK > 1, while others are categorized as "successful" if the MK value is in the range 0 to 1. The failure mode used is equation 1, a combination of axial stress (tension or compression) and bending stress (API 2A-WSD).

$$\frac{f_a}{F_a} + \frac{\sqrt{f_{bx}^2 + f_{by}^2}}{F_b} \leq 1.0 \qquad (1)$$

In determining the failure mode above, it is essential to understand the random variables involved in the failure mode equation. The variables determined in the Monte Carlo simulation are fa, fbx, fby, and Fb, with each assumed Coefficient of Variance (COV) value (Moses, 1986), which can be seen in **Table 2** and **Table 3**.

Monte Carlo simulation transforms the Random Number Generator (RNG) for each variable, and making it a probability density function of failure is an important thing in carrying out this simulation. Transformation of random numbers into random variables in MS. Excel can be done using the following function:

- Lognormal distribution
  = LOGNORMAL.INV(random_number; mean; standard_deviation)
- Normal Distribution
  = NORMINV(random_number; mean; standard_deviation).

Table 2. Determination of environmental operating condition variables

Variable	Mean	Standard Deviation	Coefficient of Variant	Distribution
fa	4.237	0.294	0.30	lognormal
fbx	4.972	0.294	0.30	lognormal
fby	4.244	0.294	0.30	lognormal
Fa	450	67.500	0.15	normal
Fb	345	51.750	0.15	normal

Table 3. Determination of Extreme Environmental Condition Variables

Variable	Mean	Standard Deviation	Coefficient of Variant	Distribution
fa	4.334	0.294	0.30	lognormal
fbx	4.813	0.294	0.30	lognormal
fby	3.985	0.294	0.30	lognormal
Fa	450	67.500	0.15	normal
Fb	345	51.750	0.15	normal

In Monte Carlo Simulation, experiments are carried out by calling random numbers. Repetition is carried out until the target number of n simulations is reached, and a record of the number of failed structures is obtained. So, the PoF (probability of failure) equation is as follows:

$$PoF = \frac{number\ of\ failure}{number\ of\ simulation\ (n)} \quad (2)$$

The reliability of the structure can be determined by the equation below:

$$K = 1 - PoF \quad (3)$$

Monte Carlo simulations are carried out using tabulations to make it easier, as in **Table 4** and **Table 5**. To obtain accurate results, 10,000 simulations are carried out. To determine the accuracy of the number of simulations, the PoF value is recorded for each particular number so that a reliability value tends to be obtained constant.

Table 4. Reliability in Environmental Operating conditions

Σdata	ΣSucces	ΣFail	PoS	PoF	K
100	99	1	0.99	0	1.0
500	496	4	0.992	0	1.0
1000	983	17	0.9830	0	0.9830
5000	4929	71	0.9858	0.0142	0.9858
10000	9876	124	0.9876	0.0124	0.9876

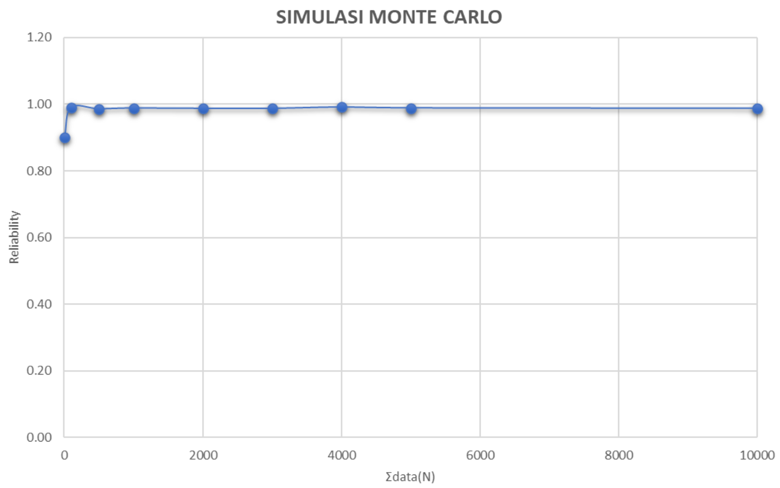

Figure 4. First Monte Carlo simulation results

Table 5. Reliability in Extreme Environmental Conditions

Σdata	ΣSucces	ΣFail	PoS	PoF	K
100	99	1	0.99	0	1.0
500	498	2	0.996	0	1.0
1000	994	6	0.9940	0	0.9940
5000	4979	21	0.9958	0.0042	0.9958
10000	9961	39	0.9961	0.0039	0.9961

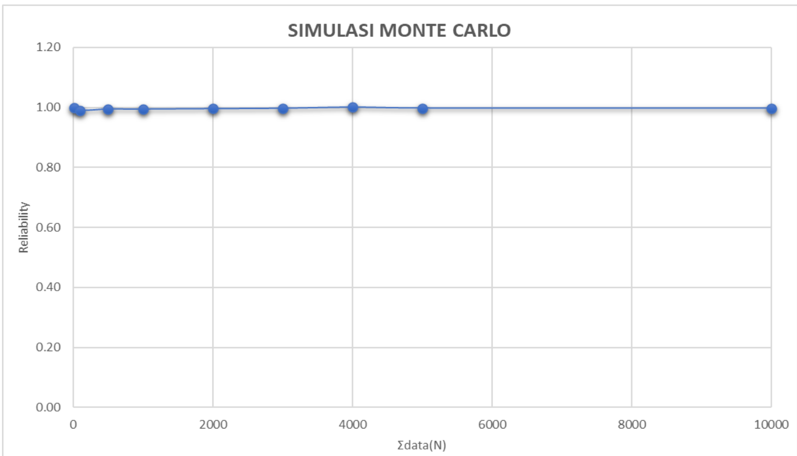

Figure 5. Second Monte Carlo simulation results

4. Conclusion

Based on the results of analysis carried out on four-legged platform jackets in the Java Sea around Gresik, Indonesia. In this research, the jacket platform has a very high level of reliability. Monte Carlo simulations were carried out 10,000 times, covering operational situations and extreme environmental conditions. The results show that the probability of failure under environmental operating conditions, the probability of failure (PoF) is 0.0039 with a reliability factor (K) of 0.9883, while in extreme environmental conditions, the probability of failure (PoF) is 0.0037 with a K of 0.9963. With these findings, the jacket platform has proven reliable in dealing with various conditions and loads that may occur. This conclusion is critical because it indicates that the structure can maintain optimal safety and performance, especially in a challenging maritime or offshore environment. Therefore, platform jackets can be relied on as a sturdy and reliable choice for various applications.

5. Recommendation

Recommendations can be given by developing a structural reliability analysis that takes into account the potential for failure due to fatigue, so it is necessary to analyze the combined ultimate and fatigue limit reliability.

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