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ENVIRONMENTAL LOAD FACTOR CALIBRATION FOR A FIXED PLATFORM IN THE JAVA SEA

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ABSTRACT: The environmental load factor in the ISO 19902 standards is derived based on conditions in the Gulf of Mexico, which are more extreme than conditions in Indonesia. This study is a preliminary investigation of the environmental load factors appropriate for the Java Sea, as this is a region in Indonesia where many platform structures are already in operation. Evaluation of an environmental load factor for Indonesia is carried out by performing reliability analyses using Monte Carlo simulations, in which the failure performance is determined by the first yield stress condition in the critical member of two fixed platform structures. From the results, an appropriate environmental load factor of 1.16 is proposed for the Java Sea, which is smaller than the value given in the ISO 20002 Standard for the Gulf of Mexico. More comprehensive environmental load factor research for other Indonesian regions should be done to complement this result.

Keywords: Environmental Load Factor, Load Resistance and Factor Design, Fixed Platform, Reliability Analysis

1. INTRODUCTION

In the design process for a steel fixed platform, there are currently two methods that can be used: the Working Stress Design (WSD) method and the Load and Resistance Factor Design (LRFD) method. These design methods each have their own way of implementing safety factors. The LRFD method is often considered to be more realistic as it implements different load factors and capacity reduction factors for each type of load and capacity, and these factors are based on the uncertainty of each load and capacity. In contrast, the applied safety factor in the WSD method does not consider the uncertainty of each load and capacity [1]. In addition, the WSD method also assumes the load variables and structural resistance are deterministic variables [2].

The WSD method is the most commonly used method by Indonesian engineers because it is simpler to apply than the LRFD method. However, Van de Graaf, et al. [3] compared the design of a fixed platform using the WSD and LRFD methods with similar input parameters, and the results indicated that the fixed platform designed using the LRFD method was 19% lighter than that designed with the WSD method. This reduction of structural weight reduces the amount of material required, and thus material costs will be more economical if the LRFD method is used instead of the WSD method.

The LRFD method was further developed by in the ISO 19902 standard, in which the environmental load factor is derived from water conditions in the Gulf of Mexico (GOM) region. The structural design process should adopt parameters that are calibrated to the surrounding environmental conditions in which the structure will be constructed [4]. The randomness of Indonesian waters clearly differs from the Gulf of Mexico owing to seasonal differences. In addition, Gulf of Mexico waters have more extreme environmental conditions than Indonesian waters, and the waves in the Gulf of Mexico can be 12.05 m high [5]. Based on these differing conditions, it is important to conduct research to determine an environmental load factor that is appropriate to use for design in Indonesian waters.

Although the environmental load is a combination of currents, winds, and waves, the dominant factor is the waves [6]. In this study, the environmental load factor is analyzed based on the uncertainty of waves occurring in the Java Sea. The load factor is assessed based on reliability analyses of two fixed platforms operating in the region, using a performance function on the tension failure of the critical member for in-place storm condition analysis results. In addition to the randomness of the wave parameters, this study also applied randomness in the yield strength of steel materials as one of the structural capacity parameters. Before proposing appropriate load factor values for Java Sea waters, this study first evaluated the application of the environmental load factor from ISO 19902, which was derived from the Gulf of Mexico, to the waters of the Java Sea.

Research has been conducted on regional environmental load factors using reliability analyses for Malaysian waters [2, 7, 8]. The results of these studies suggest that the environmental load factor for Malaysian waters is smaller than that calibrated to Gulf of Mexico waters.

By using an environmental load factor that is suitable for conditions in Indonesian waters, the design process for offshore structures can be expected to provide more optimal results. The results of this comprehensive research on environmental load factors for Indonesian waters can then be used as an input to ISO Standard Annex C [4] for implementation in offshore platform design using the LRFD method in Indonesian waters.

This study aims to identify whether application of the environmental load factor listed in ISO 19902 is suitable for the Java Sea and to suggest a recommended environmental load factor to be used for designing fixed platforms with the LRFD method in the Java Sea.

2. LITERATURE REVIEW

The differences between the WSD and LRFD methods lie in the way the structural capacity is chosen and how they compensate for the uncertainty inherent in the load and capacity of the structure. For the nominal structural capacity, the LRFD method uses the ultimate tensile strength of the material as an approximation of the nominal structural capacity, whereas the WSD method uses the yield stress of the material as its nominal structural capacity. It is clear that the LRFD method has an advantage in this respect because the ultimate tensile strength is greater than the yield stress of a material.

The WSD method depends on a single safety factor which is based on engineering judgment and field experience, regardless of the uncertainty of the load and the structural resistance. The WSD method defines all load variables and structural resistance as deterministic variables. In contrast, the LRFD method is based on a structural reliability analysis, and the method takes into account the natural uncertainty inherent in the applied load and component resistance [9]. This is another advantage of the LRFD method because the structural safety can be defined by applying different safety factor values for each load type (see Eq.(1)), where each safety factor value represents a difference in the degree of uncertainty [8]. Therefore, it can be concluded that the LRFD method is highly capable of representing the uncertainty with partial factors for the structural resistance capacity and the loads.

$$\phi R_n \geq \sum Q_i \gamma_i \quad (1) \qquad (1)$$

where ϕ is the resistance factor, R_n is the nominal structural resistance or strength, γ_i is the load factor, and Q_i is the load effect.

The ISO 19902 standard specifies the environmental load and resistance factor for steel fixed offshore platform components using the Gulf of Mexico (GOM) environmental calibration, and the recommended environmental load factor for pre-service design in storm conditions is 1.35. Studies on developing an environmental load factor suitable for application with the LRFD method in Indonesian waters have previously been performed for different types of platforms in various sea regions. The results of these studies indicate that an environmental load factor that is smaller than that given in the LRFD standard code (API RP2A-LRFD) should be used for the environmental conditions in Indonesian waters [10, 11]. Studies of partial environmental load factor calibration using reliability analyses have been extensively conducted for Malaysian waters, as listed in Table 1.

Table 1 Environmental Load Factor Calibration Results for Malaysian Waters

Author(s)	Environmental Load Factor
Nizamani et al. [2]	1.25
Cossa, Potty, and Liew [12]	1.29
Nichols et al. [8]	1.245, 1.295, and 1.255

From the studies of environmental load factor calibration conducted for Malaysian waters (listed in Table 1), it can be seen that the resulting environmental load factors are less than that listed in ISO 19902. This smaller environmental load factor is a result of the more benign environment in Malaysia waters than in Gulf of Mexico waters. For Indonesian waters, the environmental load factors may be similar or even smaller than those for Malaysian waters because Indonesian waters are mostly closed waters.

For developing an environmental load factor, several methods to perform the reliability analysis have been developed, such as fully distributional approach method, first order reliability method I and II (FORM I and II), and simulation method. Reliability analysis also requires the performance failure to be reviewed. For offshore structure, the performance failures include member failure due to environmental load, structural collapse failure, and fatigue failure in the structural joint. Study on fatigue reliability index had been performed for jacket offshore platform in Indonesia [13]. In this study, fatigue reliability analysis was performed based on fracture mechanics. It resulted that the older the ages of the structures, the smaller its reliability index value would become.

3. METHODOLOGY

The methodology used in this study is depicted in Fig. 1. Calibration of the environmental load factor for Indonesian waters was accomplished with Monte Carlo simulations of two fixed platforms: a three-legged bridge fixed platform and a four-legged wellhead fixed platform. The performance function used in this study is the first yield stress condition of the critical member during in-place analysis for storm conditions. The critical member is defined as the member of platform pile groups that has highest unity check value, as this member is considered to have a significant impact on the structural collapse failure. The inputs consisted of 100 different sets of wave heights, wave periods, and yield strengths of the steel material, and the values for these three input parameters were obtained from data generated using their associated statistical distribution types and parameters.

The Monte Carlo simulation used 100 static in-place structural analysis simulations in storm conditions to obtain 100 different unity check (UC) ratio values, as the parameter that shows the stress condition. If the 100 analysis simulations do not result in a structural failure, whereas the UC ratio value exceeds 1, it would mean that the probability of failure (PoF) of the critical member is less than 10^{-2}. Therefore, the resulted UC ratio data will be treated as a statistical data which its statistic parameters and distribution can be determined through Kolmogorov-Smirnov (K-S) test. The probability of failure (PoF) of the structure is then can be approximated as the probability when the UC

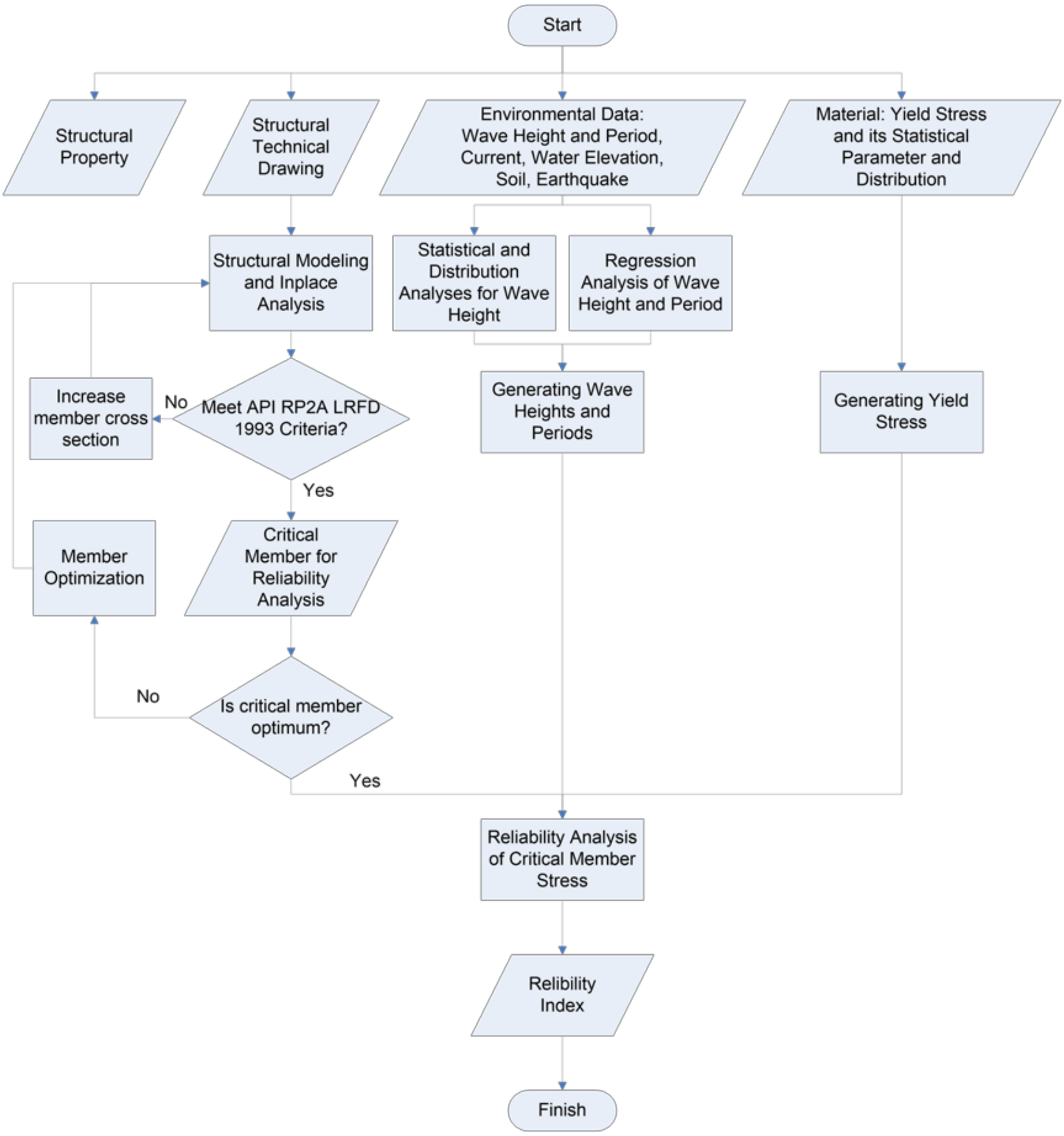

Fig.1 Methodology flowchart

ratio exceeds 1 and afterward, the index reliability, β, can be calculated.

The wave statistical distribution type and parameters were determined using a 60-year hindcasting wave dataset from the Java Sea, while the yield strength statistical distribution type and parameters were obtained from the ISO 19902 standard code. The critical member was determined based on the results of the in-place analysis in storm conditions by using deterministic design parameters.

Evaluation of the application of the environmental load factor from ISO 1990 in the Java Sea was done by conducting a reliability analysis on a structure having a critical member that was designed optimally using the LRFD method with the load factor listed in ISO 19902. The reliability index (β) obtained from this analysis with the LRFD method was then compared to the reliability index obtained by performing the same analysis on a structure whose critical member was designed optimally using the WSD method. By considering the WSD reliability index as the target value, it can be determined whether the application of the LRFD environmental load factor from ISO 19902 is overvalued for fixed platforms in the Java Sea. In addition to evaluating the application of the ISO 19902 environmental load factor in the Java Sea, the proposed environmental load factor value was also assessed with reliability analyses where the critical member was optimized for three different environmental load factors: 1.2, 1.1, and 1. From the reliability indices associated with the different environmental load factor values, an approximate equation could be obtained expressing the relationship between the environmental load factor and the reliability index of a fixed platform. Based on this approximation, a suggested environmental load factor appropriate for environmental conditions in the Java Sea was calculated based on the target reliability index obtained from the WSD method reliability analysis.

4. CASE STUDY

The location of the case study is shown in Fig. 2, where the red dot is the location of the studied platforms in the Java Sea. The platforms consisted of a three-legged bridge fixed platform and a four-legged wellhead fixed platform, which are illustrated in Fig. 3. The structural and environmental parameters for each platform are summarized in Tables 2–4.

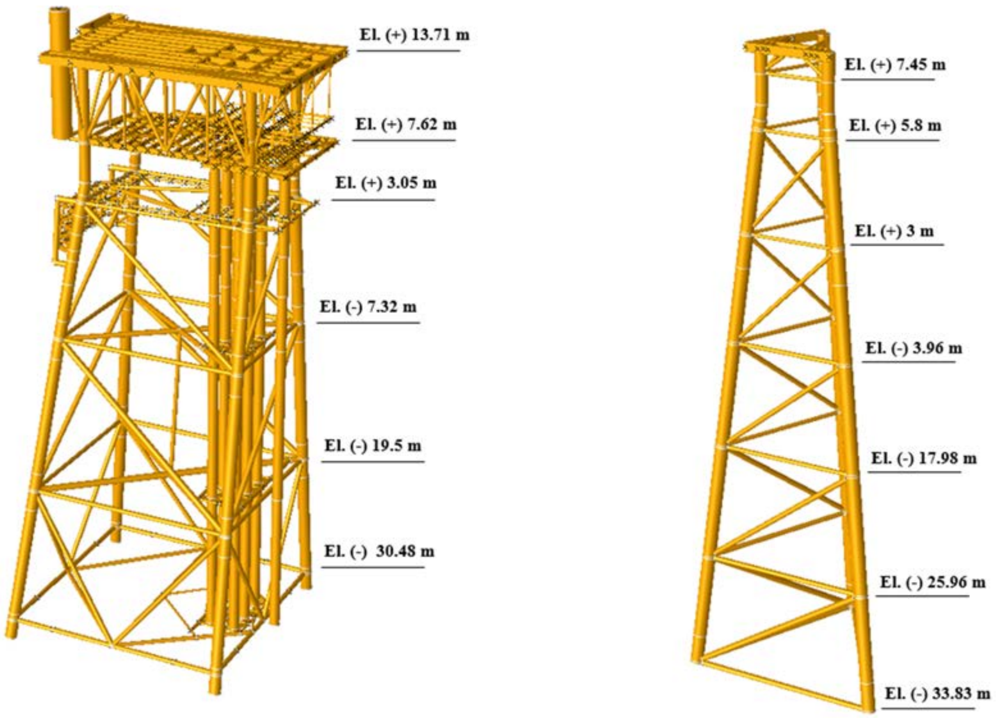

Fig.3 Illustration of Platform A (left) and Platform B (right)

Fig.2 Case study location marked with a red dot

Table 2 Structural Parameters of The Platforms

Parameter	Platform A	Platform B
Yield Strength, f_y	36 ksi	36 ksi
Distribution of f_y	lognormal	lognormal
Mean Coefficient [14]	1.13	1.13
COV [14]	0.057	0.057
Legs	4	3

Table 3 Structural Parameters of The Platforms

Parameter	Platform A	Platform B
Water depth	30.48 m	33.83 m
H_{max100}	5.91 m	8.9 m
T_{p100}	14.17 s	19.92 s

Table 4 Current Velocity at Each Depth

Parameter	% depth	100-year Storm Design (m/s)
Current	0	0.368
	10	0.457
	20	0.518
	30	0.564
	40	0.600
	50	0.622
	60	0.640
	70	0.652
	80	0.661
	90	0.671
	100	0.689

5. UNCERTAINTIES IN ENVIRONMENTAL PARAMETERS

According to Nizamani, et al. [2], wave parameters may be considered as the only random variable in the reliability analysis. Generally, the high variability of the environmental load due to the uncertainty of wind, current, and wave, may cause higher environmental loads than the designed loads. Hence the overloading effect may cause the failure of the jacket platform. According to Wen and Banaon [15], wind force acting on the offshore platform is usually equal to 10% of the acting wave force at most. Additionally, the current that is acting on the platform's legs only causes an increase that is less than 10% of the total wave force [16]. Therefore, the wind and a current parameter of this study were assumed to be deterministic. On the other hand, ocean waves are one of the most changeable phenomena on earth due to their irregularity. Thus, the variance of the wave force acting on the jacket platform is always high and hence the wave parameter cannot be considered as deterministic.

6. UNCERTAINTIES IN THE STRUCTURAL RESISTANCE

The structural resistance originates from the material properties and geometric parameters that have inherent uncertainties as well. These uncertainties will definitely lead to the variability of the structural resistance, which ultimately will give a significant effect on the platform's reliability. It is widely recognized that the variations of material properties and geometric parameters originate from human error during the design, construction, and operation process. Fortunately, the variations of material properties and geometric parameters have been extensively addressed by many studies that were done in the past and hence the variability is recently well understood.

The uncertainty modeling of the resistance based on the fabrication data of a jacket platform in Malaysia indicated that the resulted mean values from the model were higher by a small margin as compared to the ISO 19902. However, the resulted COV WAS 0.05, which is considerably smaller than the listed COV in the ISO 19902. The small variability of the structural resistance indicates that higher reliability of the platform may be achieved. According to Holický, et al. [17], lognormal distribution often provides a suitable probabilistic description of the structural uncertainty.

7. RELIABILITY ANALYSIS

Reliability analysis can be used to estimate how likely it is that design criteria will not be met by taking into account the variability of design parameters such as material properties and wave heights. The basic reliability analysis evaluates the failure of a structure based on whether a performance function has been exceeded. The performance function represents the margin between the resistance and the loads acting on the structure, and is typically expressed as follows:

$$P_f = P\{g(R,Q) < 0\} \tag{2}$$

where *R* is the resistance or structural capacity of the platform, and *Q* is the load effect that may cause structural failure. By definition, the performance or failure function, *g(R,Q)*, is then defined as:

$$g(R,Q) = R - Q \tag{3}$$

The reliability index, β, is the inverse of the probability of failure (P_f) obtained from the performance function. Therefore, it is formulated as:

$$\beta = \Phi^{-1}(P_f) \tag{4}$$

8. RELIABILITY ANALYSIS RESULTS

Fig. 4 shows the relationship between wave height and wave period in the Java Sea. Fig. 5 shows the results of a Kolmogorov–Smirnov (K-S) test for significant wave heights occurring in the Java Sea over 60 years. Based on the results, the wave height distribution is fit best as a lognormal distribution with a coefficient of variation (COV) of 0.189.

Reliability analyses were conducted for Platform A and Platform B optimized for the WSD method. Additional reliability analyses were also conducted for Platform A and B optimized for the LRFD method using the environmental load factor, γ, of 1.35 as the environmental load factor specified in ISO 19902 for storm condition. These reliability analyses were performed to determine whether there is a significant difference between the reliability indices for the LRFD and WSD methods.

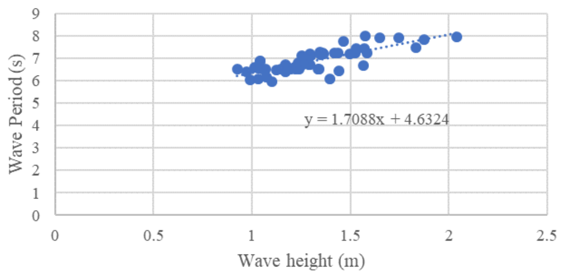

Fig.4 Relationship between wave height and wave period in the Java Sea

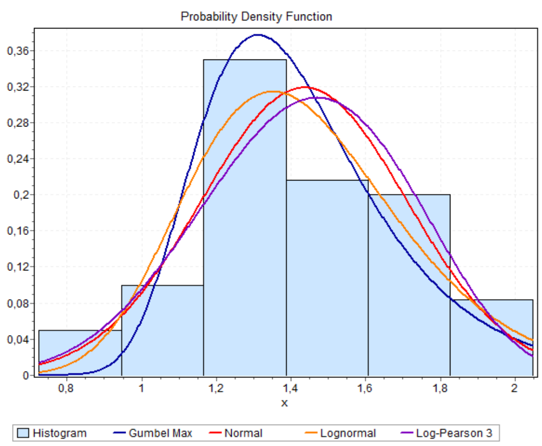

Fig.5 Probability distribution function of the wave height from a K-S test

In this study, the calculation of the probability of failure from Monte Carlo simulation was modified by determining the probability distribution function of unity check (UC) as the parameter showing the first yield stress condition. The K-S test results shown in Fig. 6 indicates that the unity check (UC) for the critical members with the WSD method, was the best fit with a lognormal distribution type. The same distribution type also resulted in LRFD method.

For Platform A, the COV for the WSD and LRFD methods are 0.165 and 0.09, respectively. For platform B, the COV for the WSD and LRFD methods are 0.151 and 0.195, respectively. The reliability index of the structure for each method could be calculated using the results of the K-S tests. The results indicate that the reliability indices for Platform A optimized to the WSD and LRFD methods were 8.2 and 9.03, respectively. The reliability indices for Platform B optimized to the WSD and LRFD methods were 11.58 and 16.397, respectively. The reliability indices for both platforms indicated that for the environmental load factor of $\gamma = 1.35$, the reliability index for the LRFD method is higher than the WSD method. This means that application of the environmental load factor from ISO 19902 would lead to an overdesigned fixed platform on the Java Sea. Therefore, the next step in this study was to calibrate an environmental load factor for the LRFD method that produces a reliability index that is the same as using the WSD method as the target reliability index. **T**he critical member unity check values for the WSD and LRFD methods using varying environmental load factors for optimization of each step are the best fit with a lognormal distribution. The statistical parameters of the fixed platforms for each environmental load factor are listed in Table 5.

According to the equations shown in Fig. 7 and Fig. 8, the environmental load factors for the LRFD method that reaches the target reliability index values were 1.16 and 0.067 for Platform A and Platform B, respectively.

9. CONCLUSION

Reliability analyses were performed for two fixed platform structures in the Java Sea, in which the failure performance was observed from the stress condition in the critical member and the analysis was performed by taking into account the randomness of the wave parameters and the yield stress of steel materials. From the results, the following conclusions can be made:

1. The reliability index value for a structure whose critical member is designed optimally using the LRFD method with an environmental load factor in accordance with ISO 19902 is greater than the reliability index for the same structure in which the critical member is designed optimally using the WSD method. This shows that the application of environmental load factors from ISO 19902 in the Java Sea results in overdesigned structures.
2. Based on the simulation results for varying environmental load factors, this study proposes

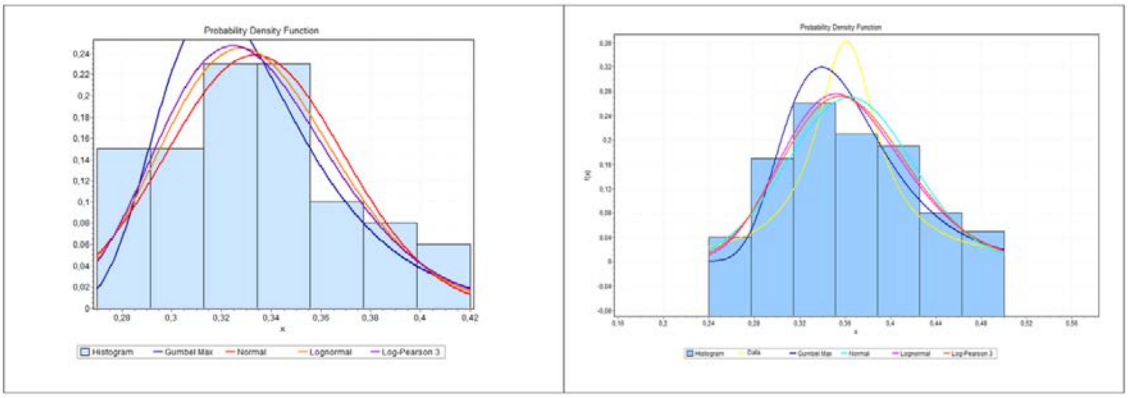

Fig. 6 Probability distribution function of unity check (WSD) in K-S tests for Platform A (left) and Platform B (right)

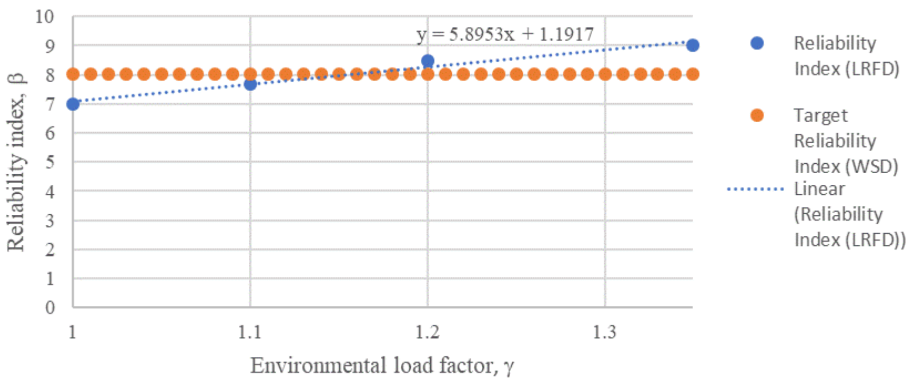

Fig. 7 Relationship between the environmental load factor and the reliability index for Platform A

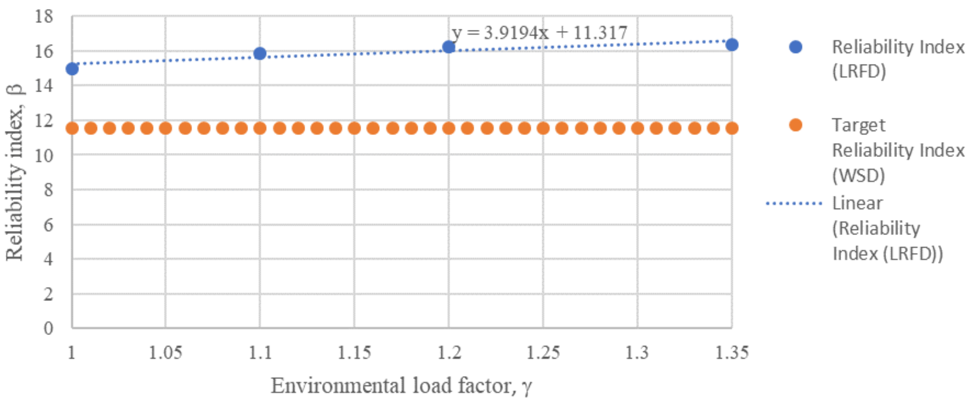

Fig. 8 Relationship between the environmental load factor and the reliability index for Platform B

a value of 1.16 as an appropriate environmental load factor for the Java Sea.

3. Further studies on environmental load factors are required for other Indonesian regions and other failure performances to obtain a comprehensive conclusion as an input to ISO Standard Annex C for regional information for the design of offshore structures in Indonesia.

10. RECOMMENDATIONS

The reliability analysis of this study was limited by the lack of simulation numbers; however, this limitation was handled by treating the simulation results as a statistical data. In this study, K-S test was performed on the resulted UC ratios to determine the distribution type and statistical parameters of the UC ratio. Afterward, the probability of failure (when UC > 1) and structural reliability could be calculated. Instead of treating the UC ratio as statistical data, it would be better if more simulations are done instead. Therefore, an explicit performance function of the structural failure should be defined beforehand so that the Monte Carlo simulation can be done for more simulations.

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