International Journal of GEOMATE, Nov., 2023 Vol.25, Issue 111, pp. 94-103
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.111.4010
Geotechnique, Construction Materials and Environment

DETERMINATION OF LRFD ENVIRONMENTAL LOAD FACTORS OF OFFSHORE PLATFORM IN THE NORTH OF JAVA SEA AND MAKASSAR STRAIT

Paramashanti[1], Rildova[1], *Mochammad Fathurridho Hermanto[2], and Nafisa Nandalianadhira[2]

[1]Ocean Engineering Department, Institut Teknologi Bandung, Indonesia;
[2]Ocean Engineering Department, Institut Teknologi Sumatera, Indonesia

*Corresponding Author, Received: 07 July 2023, Revised: 11 Sep. 2023, Accepted: 17 Sep. 2023

ABSTRACT: The environmental load factor in commonly used offshore platforms design code, API RP-2A (American Petroleum Institute - Recommended Practice 2A), is developed based on the environmental conditions of American waters, especially the Gulf of Mexico, which have relatively extreme environmental conditions when compared to Indonesian waters. Case studies were conducted to determine environmental load factors in Indonesian waters, particularly the North Java Sea and Makassar Strait, categorized as shallow seas. This analysis was carried out on the performance criteria of pushover failure. In this study, the base shear was analyzed to describe the strength of the structure in the form of a collapse base shear (CBS) and the load in the form of a wave base shear (WBS). CBS was obtained through pushover analysis with yield strength randomness. WBS was obtained through in-place analysis with wave height randomness. This concept was applied to the structure of the Monopod and Braced Monopod types of offshore platforms located in the North of Java Sea and Makassar Strait waters which had been optimized for the WSD and LRFD design methods. The reliability of the structure was analyzed based on the CBS and WBS values using the First Order Reliability Method (FORM) II. The reliability analysis results were in the form of a reliability index (β). North Java Sea gives a reliability index in the range from 3.58 to 4.38 for every design criteria. While Makassar Strait gives a reliability index in the range from 3.17 to 3.54 for every design criteria. With a high target safety level for the North Java Sea location, a 1.10 environmental load factor is recommended for further offshore structure design. But, for the Makassar Strait location, more studies need to be done to get better environmental load factor recommendations.

Keywords: Environmental Load Factor, Fixed Offshore Structure, Reliability Analysis, Pushover Analysis, LRFD, WSD

1. INTRODUCTION

The structure of the Offshore Platform must be designed following design principles, be efficient, and meet national and internationally recognized standards. The standard commonly used in the design of offshore platforms is API RP-2A (American Petroleum Institute - Recommended Practice 2A). In API RP-2A LRFD [1], the environmental load factor is developed based on the environmental conditions of American waters, especially the Gulf of Mexico, which have relatively extreme environmental conditions when compared to Indonesian waters. This makes it possible for them to be unsuitable for application in Indonesian territorial waters and makes offshore platforms inefficient. Therefore, it is necessary to conduct a study that examines the environmental load factors that are suitable to be applied in Indonesia.

The design principles and efficiency of offshore platforms are paramount, necessitating adherence to recognized standards such as API RP-2A. However, it is crucial to acknowledge that these standards, developed primarily for American waters like the Gulf of Mexico, might not be directly applicable or efficient in the context of Indonesian waters.

There are over 500 offshore platforms located across Indonesian waters and some water still has huge potential [2, 3]. Two productive oil-producing waters in Indonesia are the North Java Sea, with a depth of 45 meters below sea level, and Makassar Strait with a depth of 50 meters below sea level [4–6]. Both waters are categorized as shallow waters. The significant wave height in the North Java Sea reaches 3.55 m and 3.73 m in Makassar Strait based on SEAFINE data [7], while the significant wave height recorded from 2002 to 2006 in the Gulf of Mexico has a maximum value of 12.05 m [8]. Other research states that a 100-year return period of significant wave height in that sea reaches 21.5 m [9, 10]. Consequently, a pressing need exists to investigate and determine environmental load factors that are specifically suitable for application in Indonesian waters which have far wave height compared to the Gulf of Mexico.

In this research, a study was carried out to examine environmental load factors in two waters in Indonesia, the North Java Sea and Makassar Strait. Other similar research was done in the Nigerian Sea, and the Gulf of Mexico itself [11, 12]. Similar research has not been done in this water area. Therefore, the study was conducted to obtain the optimal environmental load factor using the reliability analysis method of the structure. A reliability analysis must be performed using a specific failure condition or performance. Several performance conditions may be applied to offshore structures as fatigue performance [13–17], structural dynamic response [18], pushover collapse [19], and member stresses [20, 21].

In this research, reliability analyses are performed on the performance criteria of pushover collapse failure and stress performance. In the performance criteria of pushover collapse failure, the structure is given maximum strength until just before the structure reaches collapse from wave loading.

This research addresses this critical knowledge gap by examining the environmental load factors in Indonesian waters. Using reliability analysis methods, this research aims to determine the optimum environmental load factor for offshore platform design in Indonesian waters.

This study will not only enhance our understanding of offshore platform design in Indonesian waters but also contribute to the development of more cost-effective and economically feasible structures in the future.

2. RESEARCH SIGNIFICANCE

The environmental load factor that is suitable for application in Indonesian water will produce less weight offshore platform structure. This research, and the following with the same aim, will make the environmental load factor more comprehensive for Indonesian water. As the structure becomes lighter, the cost of construction becomes cheaper. This will make more structure to be economically feasible in Indonesian water.

3. METHODOLOGY

3.1 Wave Data

Wave data used in this study came from SEAFINE. SEAFINE itself is a wave data modeling based on wind data (hindcasting) in the South China Sea [7, 22]. The location to be analyzed in this study is the North Java Sea at -6.726°S and 112.784°E and Makassar Strait at -0.702°S and 117.796°E.

The wave data used are significant hourly data in 58 years. The data can be analyzed for statistical parameters and the frequency of occurrence can be analyzed with a histogram. 58 years of wave data are approximated by theoretical distribution theory. The theoretical distributions used include Normal, Lognormal, Gumbel, Weibull, and Rayleigh. The most suitable theoretical distribution is determined based on the goodness of fit test [23].

There are 2 methods of the goodness of fit test conducted in this study, the Kolmogorov-Smirnov (KS) and Chi-Square. Kolmogorov-Smirnov method gives the result from the maximum difference between the theoretical and the observations cumulative density function [24]. While Chi-Square takes into account the difference between expected and observed frequencies [25].

The relationship between significant wave height and maximum wave height can be determined based on Eq. (1) for the design of offshore structures [26].

$$H_{max} = 2H_s \quad (1)$$

3.2 Structure Modeling

Two types of monopod structures with the same topside in each location were considered in this research, which are unbraced monopod, which will be referred to as monopod hereafter, and braced monopod. A dead load of 1,000 kN is applied to the topside model. These structures are designed and optimized based on API RP-2A LRFD using in-place analysis. In addition, structures designed with the LRFD method with environmental load factors of 1.00, 1.10, and 1.20 are also conducted in this research. Other structures designed based on API RP-2A WSD are used for target reliability index value. The optimized design is carried out by changing the dimensions of the leg member to reach a unity check (UC) value of 1.00. For more detailed analysis, fatigue analysis may be carried out on the offshore structure [14–17, 27].

An elastic modulus of 20,000 kN/cm^2, shear modulus of 7,722 kN/cm^2, density of 7,849 tons/m^3, and yield stress of 24.8 kN/cm^2 are applied to the model. The loadings modeled in this study include the structure's own weight and buoyancy, equipment dead load, and environmental load. The research only considers the wave load as it provides the largest environmental load to the structure [8]. The wave load is modeled in 12 directions. Other environmental loads such as current and wind loads are neglected.

3.3 Static Pushover Analysis

The optimal monopod and braced-monopod offshore platform structure models were analyzed by static pushover. Wave pushover loads are applied with various load factors. The wave load (lateral) when the structure collapses compared to the design wave load (lateral) is called the Reserve Strength Ratio (RSR) [28].

The RSR value is needed to determine the extreme direction, by doing pushover static analysis with the same structure and environmental data except for the wave direction. The analysis was carried out for 12 wave directions and each collapse base shear (CBS) value was taken. From the CBS value obtained from the pushover and wave base shear (WBS) obtained from the in-place analysis, the RSR is calculated. The direction that produces the smallest RSR value is the most extreme.

After the extreme directions from each location are obtained, the pushover static analysis is carried out to find the relationship between the yield stress of the structure (f_y) and the CBS value according to the selected extreme direction. In this study, a pushover static analysis is performed 58 times for a structure with 58 different f_y values, all of which were analyzed at the extreme.

3.4 In-place Analysis

As previously stated, this analysis is performed to obtain the model response to the appropriate loads and conditions at the operating location [29]. Another result is the WBS function which is the relationship between the structure's maximum base shear and the maximum wave height that has been converted from maximum significant wave height data for 58 years. The maximum base shear value of the structures is obtained from the in-place analysis, then it is plotted against the maximum significant wave height.

3.5 Reliability Analysis

The results of static pushover analysis will be processed to obtain the structure's reliability index (β). Not only for the design process, reliability may also be used for other needs, such as determining underwater inspection [28]. The method used is the First Order Reliability Method (FORM) II. Based on the value of the reliability index (β) of the structure, the environmental load factor can be determined.

Collapse failure mode was chosen for the performance function. The limit state equation indicates the safety margin between resistance and load as in Eq. (2) [30].

$$g = R - S \leq 0 \tag{2}$$

Where g is the limit state function. Here, the CBS acted as the resistance variable (R), while the WBS acted as the internal force (S). By inserting each variable formula, the equation becomes as in Eq. (3). This equation will be used to calculate the reliability index of the structure.

$$g(f_y, H) = CBS(f_y) - WBS(H) \leq 0 \tag{3}$$

4. RESULT AND DISCUSSION

4.1 Wave Analysis

Significant wave height (H_s) and peak wave period (T_p) data in both locations were taken from SEAFINE for 58 years in 1-hour time steps. The relationship between the wave height and the wave period is determined by finding the equation that most closely matches the relationship between the wave height and the wave period or so-called curve fitting. Based on the value of the suitability of the data (R), the logarithmic equation is the closest to the equation.

Meanwhile, wave distribution analysis is carried out on Normal, Lognormal, Gumbel, and Weibull theoretical distributions. Distribution analysis was performed using the Chi-Square and Kolmogorov-Smirnov methods. The goodness of fit test result for each location is shown in Table 1, while the PDF graphs are shown in Fig.1 and Fig.2.

Based on these results, the Lognormal distribution produces the smallest error value for the North Java Sea region. On the other hand, the Gumbel distribution produces the smallest error value for the Makassar Strait region. The selected distribution's error values meet the error limits requirement.

Table 1 Goodness of fit test error value for each location

Distribution	North of Java Sea		Makassar Strait	
	Chi-Square	K-S	Chi-Square	K-S
Normal	10.08	0.09	5.38	0.13
Lognormal	6.41	0.03	2.11	0.08
Gumbel	16.44	0.05	1.41	0.04
Weibull	22.71	0.14	9.48	0.18
Error Limit	11.07	0.18	11.07	0.18

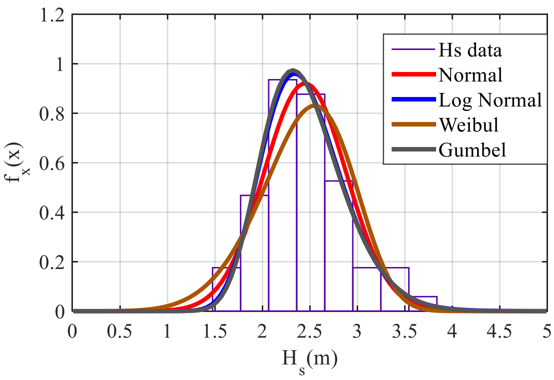

Fig.1 The probability density function of wave data and test distributions (North of Java Sea).

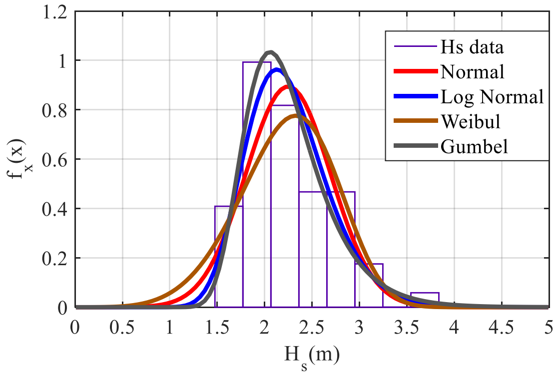

Fig.2 The probability density function of wave data and test distributions (Makassar Strait)

Based on these results, the Lognormal distribution produces the smallest error value for the North Java Sea region. On the other hand, the Gumbel distribution produces the smallest error value for the Makassar Strait region. The error values from the selected distributions meet the error limits. The concurrent results between Kolmogorov-Smirnov and Chi-Square are in line with the results of other studies [23].

Using extreme value analysis, we obtain the design wave height values, using a 100-year return period, which can be seen in Table 2. These values will be used as the only environmental load, as explained earlier, for offshore platform structure design.

Table 2 Design wave height and wave period

Parameter	Value		Unit
	North of Java Sea	Makassar Strait	
H_{max100}	7.27	7.29	meter
T_{max100}	10.20	9.50	second

4.2 Structure Modeling

The structure design models with the important elevations at each part are shown in Fig.3 for the North Java Sea and Fig.4 for the Makassar Strait. On the left is a monopod structure, while on the right is a braced monopod structure. The two areas of water give the difference in structure height.

This monopod and braced monopod structure are simpler than three-legged and four-legged structures used in some other research [31]. By using a simpler model, this study aims for results that may be more fundamental than other studies.

Using every combination of loads that will provide the maximum load, 20 structures with different leg member dimensions, outer diameter (OD), and wall thickness (WT) in each location are obtained as shown in Table 3 and Table 4.

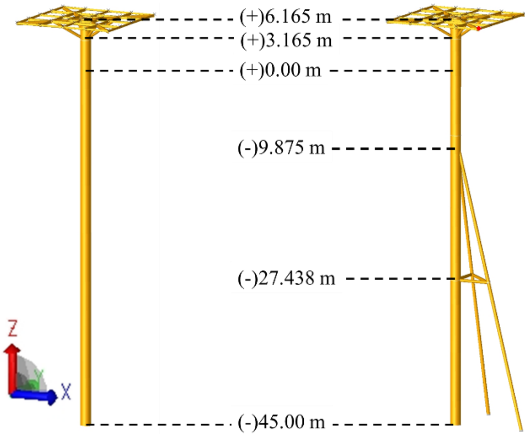

Fig.3 Structure models in the North of Java Sea (Monopod on left and Braced Monopod on right)

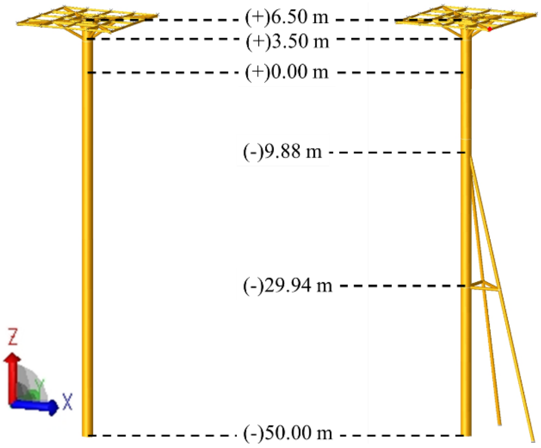

Fig.4 Structure models in the Makassar Strait (Monopod on left and Braced Monopod on right)

Table 3 Optimum structure dimensions (cm) for each criterion (North of Java Sea)

Criteria	Monopod		Braced Monopod	
	OD	WT	OD	WT
LRFD 1.00	145	1.55	1.65	0.88
LRFD 1.10	145	1.61	1.65	0.92
LRFD 1.20	145	1.67	1.65	0.95
LRFD 1.35	145	1.76	1.65	1.00
WSD	145	1.82	1.65	1.03

Table 4 Optimum structure dimensions for each criterion (Makassar Strait)

Criteria	Monopod		Braced Monopod	
	OD	WT	OD	WT
LRFD 1.00	165	1.44	1.65	1.01
LRFD 1.10	165	1.50	1.65	1.05
LRFD 1.20	165	1.57	1.65	1.08
LRFD 1.35	165	1.66	1.65	1.13
WSD	165	1.67	1.65	1.18

4.3 Pushover Analysis

Based on the extreme direction analysis, the monopod structure has an extreme direction of 180˚ while the braced monopod has an extreme direction of 30˚ in the North of the Java Sea. In Makassar Strait, the monopod structure has an extreme direction of 0˚ while the braced monopod has an extreme direction of 180˚. This wave direction is selected for the next pushover analysis using the random yield strength data.

The randomness of yield strength was generated for steel type A36 with statistical parameters in the form of a mean of 39.36 ksi (27.14 kN/cm^2), a coefficient of variation of 0.078, and a lognormal distribution [32]. A total of 58 random yield strength data is generated. For reliability analysis, the yield stress data for each location are shown in Fig.5 for the North Java Sea and Fig.6 for the Makassar Strait.

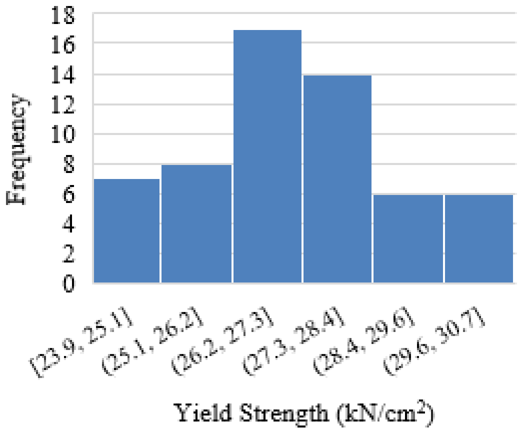

Fig.5 Yield strength histogram used for structures in the North of Java Sea

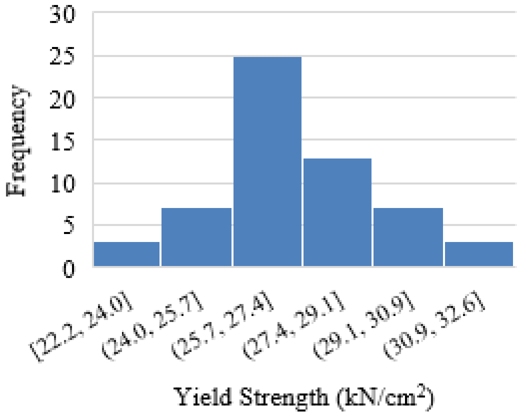

Fig.6 Yield strength histogram used for structures in Makassar Strait

Then pushover analysis is performed 58 times using the generated random yield strength data. The structure's deformations in each design are depicted in Fig.7 until Fig.8. It can be concluded that the structure designed using WSD criteria has a stronger structure, or in other words, a stronger structural capacity due to a larger cross-sectional thickness. Both monopod and braced monopod structures have the same tendency to displacement. The monopod structure failed with a large displacement, in contrast to the braced monopod structure which failed with not too large displacement.

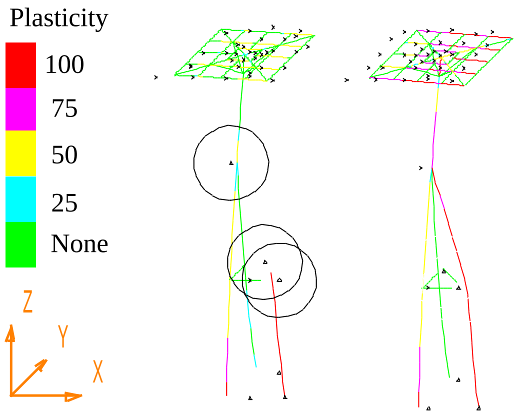

Fig.7 Typical Deformation of WSD (left) and LRFD (right) Braced Monopod

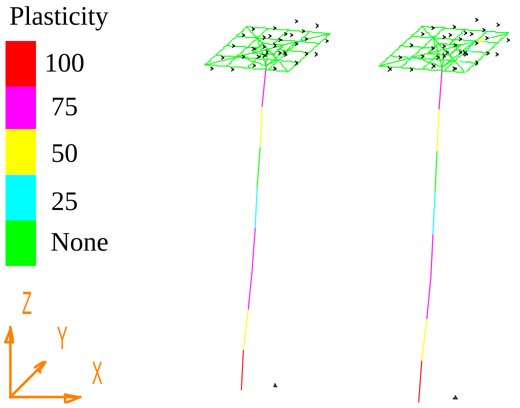

Fig.8 Typical Deformation of WSD (left) and LRFD (right) Monopod

4.4 Wave Base Shear

The relationship between the wave height and the wave base shear is shown in Fig.9 and Fig.10. Those relationships must be approached with a mathematical equation so that they can be processed to obtain a structural reliability index. The mathematical function that can approach this relationship well is the power function. This equation is shown in both graphs. Based on these results, the wave base shear gets higher when wave height gets higher.

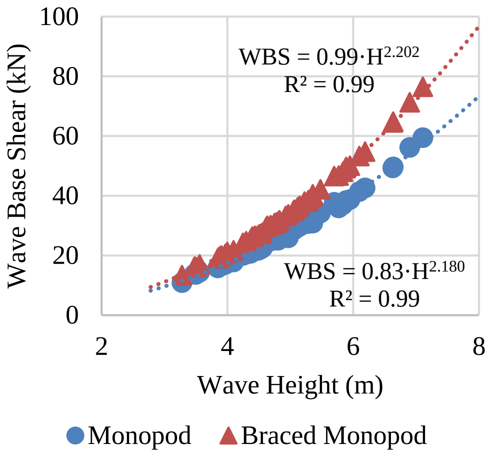

Fig.9 Relationship between the wave height and wave base shear in the North of Java Sea

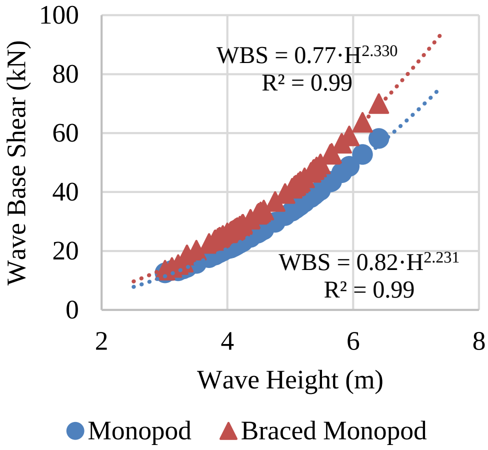

Fig.10 Relationship between the wave height and wave base shear in Makassar Strait

4.5 Reliability Analysis

The performance functions are shown in Eq. (4). The structure strength capacity parameter (R) is taken from the CBS value made in the function of f_y. The load parameter, wave load, acting on the structure (S) is obtained from the WBS value made in the function of (H). The CBS and WBS are in the form of power functions.

$$g(F_y, H) = c.f_y^d - a.H^b \leq 0 \qquad (4)$$

The CBS equation as a function of f_y is sought as the most appropriate from the line equation (trendline) from the graph plot of the 58 data sets f_y and CBS. The WBS equation is a function of H from the relationship of 58 data sets wave height and WBS.

The results from pushover analysis and in-place analysis are concluded in Table 5 and Table 6. The WBS and CBS equations from Table 5 for the North Java Sea and Table 6 for the Makassar Strait will be used for the reliability index calculation using FORM II. The results of the reliability index using FORM II are shown in Table 7 and Table 8.

Table 5 The CBS function for each design criterion in the North of Java Sea

Criteria	Monopod	Braced Monopod
LRFD 1.00	$3.01 \cdot F_y^{1.072}$	$11.85 \cdot F_y^{0.996}$
LRFD 1.10	$3.27 \cdot F_y^{1.066}$	$11.77 \cdot F_y^{0.999}$
LRFD 1.20	$3.54 \cdot F_y^{1.058}$	$12.12 \cdot F_y^{0.991}$
LRFD 1.35	$3.90 \cdot F_y^{1.053}$	$12.73 \cdot F_y^{0.977}$
WSD	$4.78 \cdot F_y^{1.026}$	$15.85 \cdot F_y^{1.001}$

Table 6 The CBS function for each design criterion in the Makassar Strait

Criteria	Monopod	Braced Monopod
LRFD 1.00	$3.47 \cdot F_y^{1.061}$	$10.40 \cdot F_y^{1.044}$
LRFD 1.10	$3.73 \cdot F_y^{1.059}$	$11.14 \cdot F_y^{1.043}$
LRFD 1.20	$4.01 \cdot F_y^{1.058}$	$12.10 \cdot F_y^{1.037}$
LRFD 1.35	$4.49 \cdot F_y^{1.049}$	$13.30 \cdot F_y^{1.035}$
WSD	$4.45 \cdot F_y^{1.054}$	$14.73 \cdot F_y^{1.028}$

Table 7 Reliability Index (β) for each design criteria in North of Java Sea

Criteria	Monopod	Braced Monopod
LRFD 1.00	3.58	5.796
LRFD 1.10	3.74	5.795
LRFD 1.20	3.88	5.80
LRFD 1.35	4.08	5.81
WSD	4.38	6.56

Table 8 Reliability Index (β) for each design criteria in Makassar Strait

Criteria	Monopod	Braced Monopod
LRFD 1.00	3.17	4.62
LRFD 1.10	3.27	4.73
LRFD 1.20	3.39	4.84
LRFD 1.35	3.53	4.99
WSD	3.54	5.13

Monopod and braced monopod structures designed in the North of the Java Sea have a greater reliability index than structures designed in Makassar Strait waters. The difference between the reliability index value of the WSD method and the

LRFD structure of the monopod and braced monopod in Makassar Strait is smaller than that of the North Java Sea.

This structure designed for both locations has a higher reliability index value than that designed for Malaysian water, 2.96 [33]. But, this reliability index is smaller compared to other structures designed for the Java Sea which has a range of 8.10 to 12.63 [31]. Compared to the 4-legged and 6-legged offshore structure designed for 3 Malaysian water with a reliability index of 3.76 and 3.72, structures for North of West Java has a bigger reliability index but for Makassar Strait is smaller [34]. Other research takes place in the Natuna Sea for the 4-legged structure that has a reliability index of 4.10 [19]. That shows that the reliability index varies for every sea.

The structure of the braced monopod in the North of the Java Sea has the same diameter as the Makassar Strait waters but with a smaller thickness. This should make the structure of the North of the Java Sea braced monopod has a smaller reliability index if all the same parameters are used. However, the structure of the braced monopod in the North of the Java Sea has a shallower depth and different water characteristics. The difference in water characteristics lies in the theoretical distribution that approximates the wave distribution. North Java Sea waves have a Lognormal distribution, while the Makassar Strait waters have a Gumbel distribution.

This also applies to the monopod structure. The monopod structure of the North Java Sea has a smaller diameter and greater thickness than the Monopod structure of the Makassar Strait waters. Although the thickness is greater, the cross-section of the North Java Sea Monopod structure has a smaller cross-section due to its smaller thickness. Similar to the reasons for the previous analysis of the braced monopod structure, these regions have differences in the theoretical distribution that are close to the distribution of wave height so that the reliability index of the structure designed in the northern part of Java waters is greater than the Makassar Strait waters.

4.6 Load Factor Analysis

The reliability index value of monopod and braced monopod structures must at least meet the normal safety class ($\beta = 3.09$) based on the recommended value [35]. In a certain condition when a failure occurs in the structure, it does not pose a risk to humans and damage to the environment. A bigger reliability index target of 3.72 is chosen for structures in the North of the Java Sea, while a reliability index target of 3.09 is chosen for structures located in Makassar Strait.

The graph of the relationship between the environmental load factor LRFD and the reliability index for the monopod and braced structure in each location can be seen in Fig.11 until Fig.14.

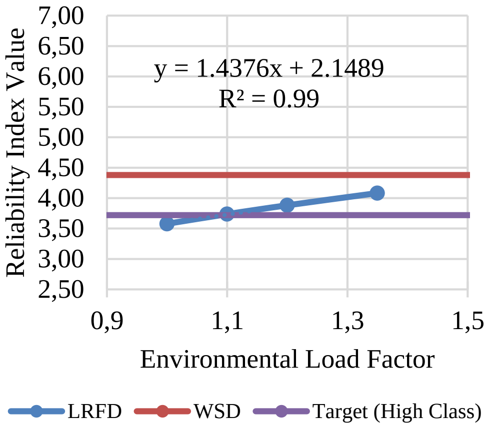

Fig.11 The LRFD environmental load factor for Monopod in the North of Java Sea

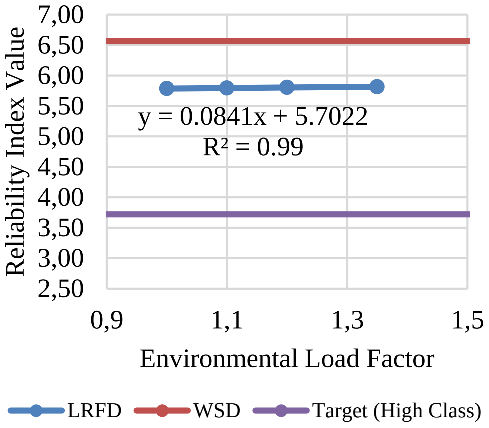

Fig.12 The LRFD environmental load factor for Braced Monopod in the North of Java Sea

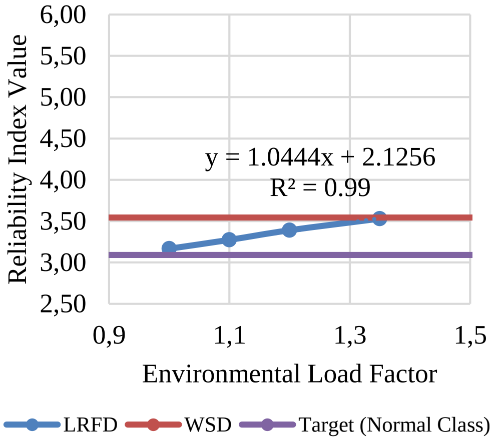

Fig.13 The LRFD environmental load factor for Monopod in Makassar Strait

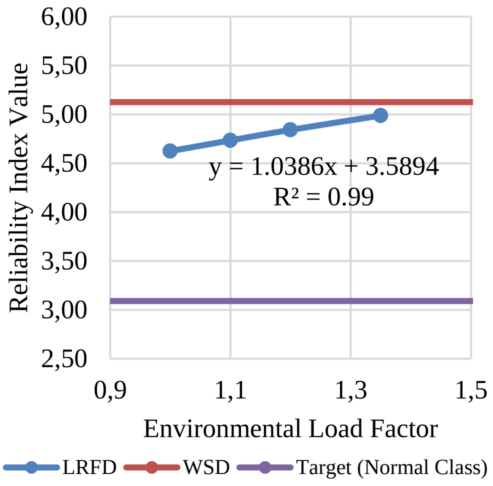

Fig.14 The LRFD environmental load factor for Braced Monopod in Makassar Strait

The reliability index of most structures exceeds the structure's reliability target, except for the monopod structure designed with LRFD factors of 1.00 and 1.10 in the North of the Java Sea. That gives an environmental load factor recommendation value of 1.10. This result is close to other research results, 1.16 for other structures in the Java Sea [31]. Therefore, both monopod and braced monopod structures in the North of the Java Sea and Makassar Strait can use a design environmental load that is smaller than the environmental load with a return period of 100 years. The structures designed with LRFD also have a lower reliability index than those designed with WSD. This result is limited to the structure type, water area, and assumptions used.

5. CONCLUSION

The recommended environmental load factor for storm conditions (γ_E) in the North of Java Sea based on a monopod is 1.10 with a high safety class target. However, there is no recommendation for a braced monopod in this water and Makassar Strait for both of structures.

The monopod and braced monopod structures in the North of the Java Sea and Makassar Strait are recommended to be designed using environmental loads with a return period of less than 100 years to produce a more efficient structure based on the reliability index target.

Further studies using varied topside weight values, deck and jacket dimensions, and more resistance parameters need to be conducted to obtain more comprehensive results. Studies using environmental loads with a return period of less than 100 years should also be conducted. The relatively calm Indonesian waters make the use of the 100-year return period less efficient.

6. REFERENCES

[1] American Petroleum Institute, Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms - Load and Resistance Factor Design, 1993.

[2] Nugraha R.B.A., Basuki R., Oh J., Cho I.H., Naibaho N., Secasari Y., and Mbay L., Rigs-To-Reef (R2R): A new initiative on re-utilization of abandoned offshore oil and gas platforms in Indonesia for marine and fisheries sectors, IOP Conference Series: Earth and Environmental Science, Vol 241, 2019, pp. 1–12.

[3] Putri H., and Salim W., The Maritime Silk Road’s potential effects on outer island development: The Natuna Islands, Indonesia, Island Studies Journal, Vol 15, Issue 2, 2020, pp. 155–172.

[4] Directorate General of Oil and Gas, Ministry of Energy and Mineral Resources, Statistic Oil and Gas Semester I 2022, 2023, pp. 1–100.

[5] Bee O.J., Offshore Oil in Indonesia, Ocean Management, Vol 6, 1980, pp. 51–73.

[6] Payenberg T.H.D., Miall A.D., Snedden J.W., Sarg J.F.R., and Peters K.E., A new geochemical– sequence stratigraphic model for the Mahakam Delta and Makassar slope, Kalimantan, Indonesia, The American Association of Petroleum Geologists, Vol 85, Issue 6, 2001, pp. 1098–1101.

[7] Wurjanto A., Mukhti J.A., and Wirasti H.D., Extreme Significant Wave Height Map of Indonesia Based on SEAFINE and ERA5 Database, Journal of Engineering and Technological Sciences, Vol 53, Issue 1, 2021, pp. 151–163.

[8] Korobkin M., and D’Sa E., Significant Wave Height in The Gulf of Mexico: Validation Of Jason-1 Measurement Against Buoy Data, 2008, pp. 1–4.

[9] Wen Y.K., and Banon H., Development of Environmental Combination Design Criteria for Fixed Platforms in the Gulf of Mexico., ‘Offshore Technology Conference’, 1991, pp. 365–375.

[10] Anh B.T., and Cuong D.Q., Strength Analysis of Fixed Steel Jacket Structure Under Dynamic Effects of Wave Loads in Vietnam Sea Conditions, International Journal of GEOMATE, Vol 24, Issue 103, 2023, pp. 1–16.

[11] Albert I.L., Orji C.U., and Morrison I., Assessment of Environmental Load Factor in the Design of Offshore Structure: Case Study of a Jacket Structure, International Research Journal of Modernization in Engineering

Technology and Science, Vol 4, Issue 10, 2022, pp. 160–169.

[12] Chen J., and Gilbert R.B., Calibration of Load and Resistance Factors of API RP 2A-LRFD, Second Edition, for Fixed Offshore Platforms, Journal of Structural Engineering, Vol 147, Issue 2, 2021, pp. 1–12.

[13] Morató A., and Sriramula S., Calibration of safety factors for offshore wind turbine support structures using fully coupled simulations, Marine Structures, Vol 75, 2021, pp. 1–25.

[14] Zhao W., Calibration of design fatigue factors for offshore structures based on fatigue test database, International Journal of Fatigue, Vol 145, 2021, pp. 1–15.

[15] Zhao W., and Hsu W.-T., Calibration of Design Fatigue Factors for Offshore Wind Turbine Support Structure Based on Fatigue Test Database, Preprints.org, 2020, pp. 1–14.

[16] Varela G., and Tolentino D., Evaluation of the Structural Reliability of a Fixed Offshore Structure over Time., Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering, 2022, pp. 1–10.

[17] Paramashanti, Rildova, Sucipto V.N.B., and Kurniawan A., Influence of random variable on reliability index of braced monopod platform based on fatigue analysis in Madura North Java Sea., IOP Conference Series: Earth and Environmental Science, 2022, pp. 1–11.

[18] Lee S.G., and Kim D.H., Reliability Analysis Offshore Wind Turbine Support Structure Under Extreme Ocean Environmental Loads, Journal of Korean Society of Coastal and Ocean Engineers, Vol 26, Issue 1, 2014, pp. 33–40.

[19] Hermanto M.F., and Nandalianadhira N., Reliability of Four Leg Fixed Offshore Platform Structure in Natuna, Rekayasa, Vol 15, Issue 3, 2022, pp. 283–291.

[20] Kim H.S., Kim H.S., Park B., and Lee K., Reliability-Based Design Optimization of 130m Class Fixed-Type Offshore Platform, Journal of the Computational Structural Engineering Institute of Korea, Vol 34, Issue 5, 2021, pp. 263–270.

[21] Kim B., and Ha S.-H., Structural Design Optimization of Gageocho Jacket Structure Considering Unity Check, Journal of the Computational Structural Engineering Institute of Korea, Vol 34, Issue 4, 2021, pp. 205–212.

[22] Muliati Y., Tawekal R.L., Wurjanto A., Kelvin J., and Pranowo W.S., Wind Wave Modeling in Natuna Sea: A Comparison Among Swan, Seafine, and Era-Interim, International Journal of GEOMATE, Vol 16, Issue 54, 2019, pp. 176–184.

[23] Rolke W., and Gongora C.G., A chi-square goodness-of-fit test for continuous distributions against a known alternative, Computational Statistics, Vol 36, Issue 3, 2021, pp. 1885–1900.

[24] Razavifar M., Mukhametdinova A., Nikooee E., Burukhin A., Rezaei A., Cheremisin A., and Riazi M., Rock Porous Structure Characterization: A Critical Assessment of Various State-of-the-Art Techniques, Transport in Porous Media, Vol 136, Issue 2, 2021, pp. 431–456.

[25] Nihan S.T., Karl Pearsons chi-square tests, Educational Research and Reviews, Vol 15, Issue 9, 2020, pp. 575–580.

[26] Goda Y., Random seas and design of maritime structures, Reprint ed., 2008, pp. 1–500.

[27] Ghiffary M.N., Murdjito M., and Prastianto R.W., Fatigue Life Comparison of Modified and Conventional 3 Leg Jacket Offshore Structure, International Journal of Offshore and Coastal Engineering, Vol 4, Issue 2, 2020, pp. 48–56.

[28] Tawekal J.R., and Tawekal R.L., Risk reliability-based underwater inspection method for jacket platforms in Indonesia, International Journal of Structural Integrity, Vol 9, Issue 5, 2018, pp. 603–615.

[29] Sadeghi K., An Overview of Design, Analysis, Construction and Installation of Offshore Petroleum Platforms Suitable for Cyprus Oil/Gas Fields, Vol 2, Issue 4, 2007, pp. 1–16.

[30] Haldar A., and Mahadevan S., Probability, reliability, and statistical methods in engineering design, 2000, pp. 1–304.

[31] Paramashanti, and Tawekal J.R., Environmental Load Factor Calibration for a Fixed Platform in the Java Sea, International Journal of GEOMATE, Vol 15, Issue 49, 2018, pp. 104–111.

[32] Hess P.E., Bruchman D., Assakkaf I.A., and Ayyub B.M., Uncertainties in Material and Geometric Strength and Load Variables, Naval Engineers Journal, Vol 114, Issue 2, 2002, pp. 139–166.

[33] Cossa N.J., Potty N.S., and Liew M.S., Development of Partial Environmental Load Factor for Design of Tubular Joints of Offshore Jacket Platforms in Malaysia, The Open Ocean Engineering Journal, Vol 6, Issue 1, 2013, pp. 8–15.

[34] Nichols N., Khan R., Rahman A., Akram M., and Chen D.K., Load resistance factor design calibration of load factors for extreme storm loading in Malaysian waters, Journal of

Marine Engineering and Technology, Vol 13, Issue 2, 2014, pp. 21–34.

[35] Bai Y., and Jin W.-L., Marine structural design, Second edition, 2016, pp. 1–977.