INTERNATIONAL JOURNAL OF
COASTAL, OFFSHORE & ENVIRONMENTAL ENGINEERING
IJCOE Vol.8/No. 2/Spring 2023 (1-12)

Available online at: www. Ijcoe.org

Reliability Analysis of Fixed Platform due to Seabed Subsidence and Wave Load in Deck

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ARTICLE INFO

Article History:
Received: 16 Jan. 2023
Accepted: 01 Mar. 2023

Keywords:
Fixed Platform
Probability of Failure
Reliability Index
Reserve Strengh Ratio
Wave in Deck

ABSTRACT

The structural integrity of fixed platform may be affected from excessive load on the structure and insufficient strength of the structure. Another factor which affects the structural integrity is seabed subsidence. Seabed subsidence occurs due to vertical movement of soil layers and soil consolidation. The impact of seabed subsidence will lead to decreased of deck clearance or air gap and cause wave hits the deck. The aim of the study is to determine the effect of wave load in deck using pushover and reliability analysis. The wave height at collapse is calculated based on the reserve strength ratio generated from pushover analysis. The wave load in deck calculation is referred to American Petroleum Institute (API). The pushover with inclusion wave load in deck is necessary to be carried out to gain the updated reserve strength ratio. The reliability analysis is computed by involving base shear of fixed platform at collapse from pushover analysis with wave load in deck. Monte Carlo simulation technique method is adopted in the analysis which generating one million data of wave height and wave period as random variables. This study also performs the probability of failure and reliability index due to wave load in deck. As expected, the updated reserve strength ratio with wave load in deck is lower than the reserve strength ratio without wave load in deck. Then, the probability of failure increases with the increase of the depth of subsidence. Therefore, the reliability index decreases with the increase of the depth of subsidence.

1.Introduction

Fixed platform is an offshore structure that is widely applied in Indonesian waters. In the design process of fixed platform structure, it is necessary to ensure the structural integrity to avoid structural failure [1]. Some factors that may affect the structural integrity of fixed platform. They are excessive load on the structure and insufficient structural strength in receiving loads [2]. Excessive load comes from environmental and accidental loads. While insufficient structural strength is happened due to design, fabrication and installation error.

As time passed, fixed platform experienced structural strength may decrease which caused by some factors such as corrosion, weld crack, scour and seabed subsidence [3], [4]. This research focuses on fixed platform that is degraded due to seabed subsidence. Seabed subsidence may occur due to vertical movement of sedimentary layers and sediment consolidation. In addition, massive exploration of petroleum and natural gas can lead to depletion of reservoirs which causing the soil compaction. The soil compaction will increase with the increase of reservoir depletion. Hence, these things lead to seabed subsidence from time to time [5].

Generally, seabed subsidence may affect the decreasing of air gap and getting worse during the extreme conditions. Seabed subsidence needs to be considered during the design process of fixed platform to avoid catastrophic incidents due to conditions where the mean sea level (MSL) becomes closer to the deck. Therefore, there is wave load scenario in deck [6].

Jafari et al. [7] studied the static and dynamic analysis due to wave in deck which considered the effect of regular and irregular wave. The study concluded that the dynamic amplification factor (DAF) tends to decrease as the significant wave crest height increase. Based on this study, the structural integrity and reliability were not the focus in the analysis.

Study performed by Nazokkar et al. [8] conducted the effect of damper on controlling the vibrations of the floating offshore under different loads with wind and wave. The wave load was calculated using modified Morison formulation with the parameter of 100-year significant wave height (H_s) and peak period (T_p). The study assumed that the wave load acted together with the wind load. However, the study did not consider the wave load in deck.

The effect of wave in deck issue on the fixed platform was performed by Yee et al. [9] using pushover analysis. The study concluded that the reserve strength ratio (RSR) and base shear were affected by some contributing factors from wave in deck. They were wave height, wave period and water depth. The wind load in deck was also considered in the pushover analysis. On top of that, the wind load was also found on contributing to the wave load in deck event. None of explanation regarding the reliability analysis of fixed platform due to wave in deck event was included in this study.

Based on the study performed by Azman et al. [10], wave load in deck was considered if the wave crest height at collapse is higher than the bottom steel elevation of the fixed platform. The study considered wave crest height at collapse by incorporating wave load in deck and investigated the impact of wave load in deck for fixed platform. The pushover analysis was utilized to determine the structural integrity of the structure. Then, the reliability-based design and assessment (RBDA) was adopted to determine the probability of failure of the structure. However, the reliability index calculation was excluded in the study.

Pushover and reliability analysis due to seabed subsidence need to be performed to determine the feasibility of structure during operation. Pushover analysis is carried out to determine the behaviour of structural collapse and reserve strength ratio (RSR). This analysis will consider the 100-year environmental load on extreme conditions. In this research, wave load in deck will be considered in pushover analysis if the wave crest height at collapse is higher than bottom of steel elevation of the lowest deck structure.

Then, reliability analysis is performed to calculate the probability of failure (P_f) and reliability index (β). Monte Carlo simulation technique method is adopted in the reliability analysis of fixed platform. In the reliability analysis, it is necessary to determine performance function / limit state to describe random variable. Environmental load on the structure is limited to wave load only which wave height and wave period are considered as random variables. These random variables have one million data that is generated by Matlab software respectively. From the calculation of the probability of failure (P_f) and reliability index (β) of fixed platform, then it can be used as a determination of the feasibility of the structure due to seabed subsidence and wave load in deck during operation.

2.Wave Load in Deck and Reserve Strength Ratio

According to the literature review, there are three methods to calculate wave load in deck. They are silhouette metthod, component method and computational fluid dynamics (CFD) method. Silhouette method is a simple method which based on projected area of wave in deck and does not require the detailed deck model. This method is referred to American Petroleum Institute Recommended Practice – Working Stress Design (API RP-2A WSD) [11]. In the other hand, component method needs detailed deck model to calculate wave load in deck [12],[13]. Then, CFD method simulates the fluid flows of wave load in deck by numerical analysis and compare the results with the laboratory experiment [14],[15].

In this study, the silhouette method is adopted to calculate wave load in deck without considering dynamic effect in the structure. Wave load in deck (F_{Deck}) is determined by formulation from API RP-2A WSD that be written in Eq. (1).

$$F_{Deck} = \frac{1}{2}\rho C_D(\alpha_{wk}V + \alpha_{cb}U)^2 A_{deck} \quad (1)$$

Where F_{Deck} is wave load in deck, ρ is density of seawater, C_D is drag coefficient, α_{wk} is wave kinematic factor (0.88 for hurricane condition and 1.0 for winter storm condition), α_{cb} is current blockage factor, V is fluid horizontal velocity, U is current velocity in line with wave and A_{deck} is projected area of wave in deck.

According to API RP-2A WSD [11], projected area of wave load in deck (A_{deck}) is calculated from bottom steel of lowest deck elevation (EL_{LD}) up to collapse wave crest elevation (EL_{WID}). Projected area of wave in deck (A_{deck}) is determined with formulation in Eq. (2) [11].

$$A_{deck} = A_{deckx}\cos\theta_w + A_{decky}\sin\theta_w \quad (2)$$

Where A_{deckx} is projected area of wave in deck in X-axis direction, A_{decky} is projected area of wave in deck in Y-axis direction and θ_w is wave direction.

Wave load in deck occurs when waves strike a platform's deck and equipment because there is no deck clearance or air gap. To avoid wave in deck, the bottom steel of the lowest deck elevation should be located at an elevation which will clear the calculated design wave crest with adequate allowance for safety. Hence, the lowest deck elevation should be designed in higher elevation [11],[16]. In order to calculate the effects of wave load in deck, the maximum wave height of fixed platform at collapse ($H_{Collapse}$) is determined using equation referred to Azman et al. [10] which is shown in Eq. (3).

$$H_{Collapse} = RSR^{\frac{1}{\alpha}}.H_{100} \quad (3)$$

Where $H_{Collapse}$ is maximum wave height of fixed platform at collapse, H_{100} is 100-year maximum wave height and α is the metaocean constant, typically 1.7 to 2.0. The $H_{Collapse}$ is used to calculate projected area of wave in deck. Then, the wave load in deck is considered in pushover analysis.

In pushover analysis, the structure is subjected to permanent load and functional load first, then followed by environmental load that want to be obtained at ultimate resistance / capacity. The environmental load is incremented until the structure is globally collapsed and generate the ultimate capacity of the structure. Thus, the determination of the ultimate capacity of the structure against load scenario is obtained. This determination system is referred to reserve strength ratio (RSR). Reserve strength ratio is defined as ratio between collapse load of fixed platform and 100-year environmental load of fixed platform, in terms of base shear [2],[17]. Therefore, the formulation of reserve strength ratio is shown in Eq. (4).

$$RSR = \frac{E_{collapse}}{E_{100}} \quad (4)$$

Where RSR is reserve strength ratio, $E_{collapse}$ is base shear of fixed platform at collapse and E_{100} is base shear of 100-year environmetal load.

3.Performance Function, Probability of Failure and Reliability Index

In reliability analysis, it is necessary to determine performance function / limit state [18]. Generally, the performance function can be written in Eq. (5).

$$Z = R - S \quad (5)$$

Where Z is performance function / limit state, which is stochastic variable, R is resistance / capacity of the structure and S is load on the structure. The failure is defined through the performance function which is negative or zero at failure [19].

In this research, R is variable describing the ultimate resistance / capacity of the structure which obtained from base shear of fixed platform at collapse ($E_{collapse}$). Meanwhile, S is variable describing the base shear of structure (E_i) in terms of random wave height (H_i) and wave period (T_i) where these random variables are generated by Matlab software. Therefore, the performance function is given in Eq. (6).

$$Z = E_{collapse} - E_i \quad (6)$$

The regression analysis is employed for formulating base shear structure (E_i). Thus, the general formulation of performance function from regression analysis is given by Eq. (7).

$$Z = E_{collapse} - (AH_i^2 + BT_i^2 + CH_i + DT_i + E) \quad (7)$$

Where A and C are coefficient of random wave height, B and D are coefficient of random wave period and E is constant. The failure occurs when base shear of fixed platform at collapse ($E_{collapse}$) is smaller than base shear of structure (E_i) in terms of random wave height (H_i) and wave period (T_i) as random variables.

The probability of failure (P_f) is computed using Monte Carlo simulation technique. According to Taheri et al. [20], this method requires thousands, millions or even more to obtain the better result. Then the probability of failure (P_f) is given in Eq. (8).

$$P_f = P\ (failure) = P\ (Z < 0) = P(R < S) \quad (8)$$

The formulation above Eq. (8) can be spelled out in the form of derivation from Eq. (7) that given by Eq. (9).

$$P_f = P\left(E_{collapse} < AH_i^2 + BT_i^2 + CH_i + DT_i + E\right) \quad (9)$$

Thus, the reliability index is obtained by Eq. (10).

$$\beta = \Phi^{-1}(1 - P_f) \quad (10)$$

Where Φ^{-1} is standard normal variate at the probability level $(1 - P_f)$.

4.Model Description

The fixed platform that be investigated in this study is 8-leg jacket type processing platform. The water depth of this fixed platform is 33.83 m. The design of this fixed platform is equipped with the facility of living quarter. The general outline of the fixed platform is shown in Figure 1. Then the overview of fixed platform specification is summarized in Table 1.

The selected fixed platform is verified against the latest basis design report, weight control report, inspection report and drawings to represent the actual condition during analysis.

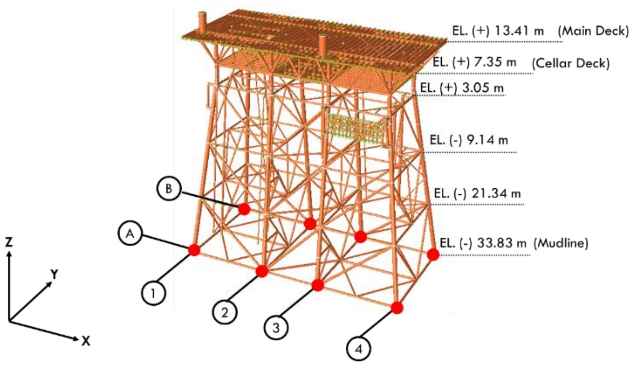

Figure 1. Structure specifications of Fixed Platform

Table 1. Fixed platform specification

Features	Description
Field Location	Java Sea (Indonesia)
Design Service Category	Processing
Design Safety Category	Manned
Installed	2004
Water Depth	33.83 m

Number of Leg	8
Number of Pile	8
Number of Riser	5
Number of Boatlanding	1

5. Research Methodology

The research methodology that be employed in this study and presented here is breaking down into the following eight steps.

i. Identification and Modelling of Fixed Platform
The latest data of fixed platform report and drawings are collected. Latest metaocean data of 100-year maximum wave height (H_{100}), associated wave period (T_{100}) and current velocity are utilized in pushover analysis. In this fixed platform, research is carried out on seabed subsidence with depth of 0 until 7 m.

ii. Pushover Analysis with Depth Variations of Seabed Subsidence
The pushover analysis is performed using SACS software by incrementing the 100-year environmental loads until the fixed platform is globally collapsed. This analysis considers the dead load, live load, and 100-year environmental load in eight directions, which are 0º, 65º, 90º, 115º, 180º, 245º, 270º and 295º. The base shear of fixed platform at collapse is obtained from this analysis. Then the reserve strength ratio can be determined based on the base shear of fixed platform at collapse ($E_{collapse}$) divided by base shear of 100-year environmental load (E_{100}) referred to Eq. (4).

iii. Air Gap Analysis
The maximum wave height of fixed platform at collapse ($H_{Collapse}$) is calculated using Eq. (3) where the reserve strength ratio is acquired in step ii. Then the maximum wave crest height of fixed platform at collapse is compared against the bottom of steel elevation of the lowest deck structure (LD_{EL}).

iv. Pushover Analysis with Depth Variations of Seabed Subsidence and Wave Load in Deck
The pushover analysis is performed again in this step if the maximum wave crest height of fixed platform at collapse is higher than bottom of steel elevation of the lowest deck structure (LD_{EL}). Next, the distance between maximum wave crest height which hitting the deck and bottom of steel elavation of the lowest deck structure (LD_{EL}) is utilized to calculate projected area of wave in deck (A_{deck}) as determined in Eq. (2). Therefore, wave load in deck for fixed platform can be calculated as per Eq. (1). In this pushover analysis, the updated base shear of fixed platform at collapse ($E_{collapse}$) and reserve strength ratio are obtained by incorporating wave load in deck.

v. Kolmogorov-Smirnov Test
The wave data which consist of wave height and wave period are taken from ERA5. Kolmogorov-Smirnov test is carried out to determine which the theoritical distributions can be accepted. Those theoritical distributions are normal, lognormal, Rayleigh and gumbel. From this test, the parameter of mean and standard deviation of accepted theoritical distributions is calculated.

vi. Generation of Random Variables
The generation of random variables which consists of wave height (H_i) and wave period (T_i) is performed using Matlab software. The parameter of mean and standard deviation is required to perform this generation. One million data of wave height (H_i) and wave period (T_i) are generated respectively by this process from Matlab software.

vii. Regression Analysis
The regression analysis is acquired to detemine the relationship between base shear of the structure (E_i) with wave height (H_i) and wave period (T_i). Then, the base shear of the structure (E_i) is defined as load on the structure variable in the performance function.

viii. Reliability Analysis
The performance function is determined by Eq. (7). From this performance function, the probability of failure (P_f) is calculated using Monte Carlo simulation technique method which is stated in Eq. (9). It can be simplified to the number of simulation cycles when Z is zero or negative divided by total number of simulation cycles. Then the reliability index (β) is computed using Eq. (10).
Next, the calculated reliability index (β) is compared with recommended target safety level which referred to Bai [21]. This recommended target safety level is shown in Table 2. The safety class is divided into three level which are low, normal, and high.

- Low safety class: where failure of component or tubular joint implies no risk to human safety and environmental damage. When a certain damage is found in this class, its condition can be monitored and no other necessary measures needs to be applied.
- Normal safety class: where failure implies negligible risk to human safety, minor danger to the main part of the platform, minor damages to the environment, certain economic loss.
- High safety class: where failure implies risk to the total safety of the platform so as to human safety and environmental pollution. High economic loss cannot be avoided.

Table 2. Recommended Target Safety Level

Safety Class	Target	Safety
Low	$P_f = 10^{-2}$	$\beta = 2.32$
Normal	$P_f = 10^{-3}$	$\beta = 3.09$
High	$P_f = 10^{-4}$	$\beta = 3.72$

6. Results and Discussions

6.1. Reserve Strength Ratio

Pushover analysis without wave load in deck is carried out to determine reserve strength ratio. From this analysis, both the lowest and highest reserve strength ratio at maximum water depth is 1.69 and 3.72 respectively. Those are shown in Figure 2 and Figure 3. Meanwhile, Figure 4 and Figure 5 capture both the lowest and highest reserve strength ratio at minimum water depth are 1.68 and 3.79 respectively.

The lowest reserve strength ratio at maximum water depth which be shown in Figure 2 occurs in conditions when the fixed platform experienced subsidence of 2 m. Then, as be seen in Figure 4 and Figure 5, both the lowest and highest reserve strength ratio at minimum water depth happen in conditions when the structure faced subsidence of 4 m and 1 m respectively.

The reserve strength ratio from pushover analysis is used to calculate the maximum wave height of fixed platform at collapse ($H_{Collapse}$).

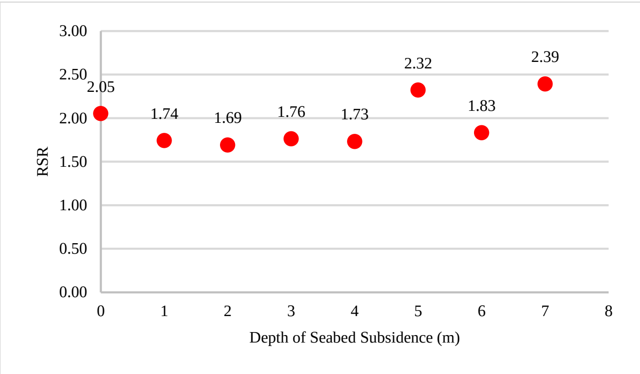

Figure 2. Reserve Strength Ratio of Fixed Platform from 90 Deg-Environmental Load at Maximum Water Depth

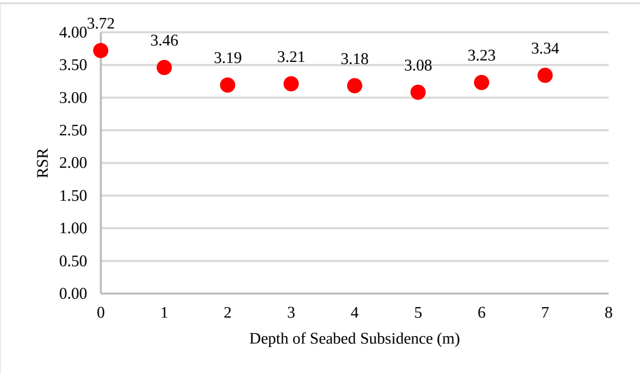

Figure 3. Reserve Strength Ratio of Fixed Platform from 180 Deg-Environmental Load at Maximum Water Depth

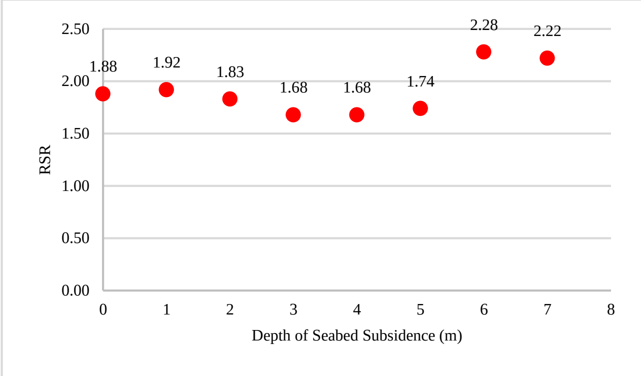

Figure 4. Reserve Strength Ratio of Fixed Platform from 90 Deg-Environmental Load at Minimum Water Depth

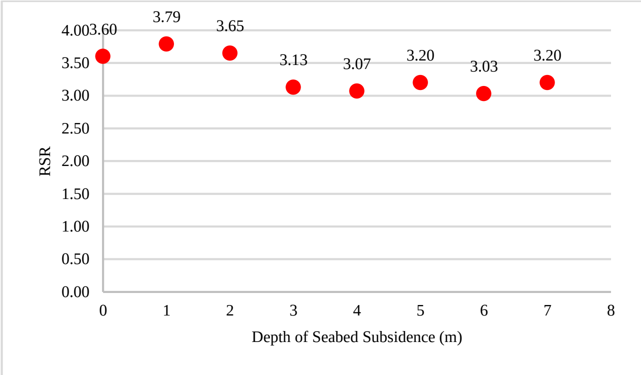

Figure 5. Reserve Strength Ratio of Fixed Platform from 180 Deg-Environmental Load at Minimum Water Depth

6.2. Maximum Wave Height at Collapse

Air gap analysis is performed to to determine whether there is wave in deck based on the reserve strength ratio from pushover analysis. The maximum wave height at collapse ($H_{Collapse}$) is calculated using Eq. (3). Next, the maximum wave crest height is compared with the bottom of steel elevation of the lowest deck structure (LD_{EL}).

Table 3 and Table 5 show that wave hitting the deck when the fixed platform is subsiding more than 0 m and 1 m by the condition of 100-year environmental load from 90º direction at both maximum and minimum water depth. Table 3 indicates that the maximum wave crest height at collapse above bottom of steel elevation is 0.71 m at the depth of subsidence of 2 m. Meanwhile, it is found in Table 5 that the maximum wave crest height at collapse above bottom of steel elevation is 0.54 m at the depth of subsidence of 1 m. Both Table 3 and Table 5 present that there are some conditions in the fixed platform that have no air gap, causing wave load in deck.

The result which are shown in

Table 4 and Table 6 describe the fixed platform is hit by wave in deck when there is no subsidence occured against the structure by 100-year enviromental load from 180º direction. Table 4 depicts that the maximum wave crest height at collapse above bottom of steel elevation is 1.51 m at no subsidence. It is also observed in Table 6 that the maximum wave crest height at collapse above bottom of steel elevation is 1.37 m at no subsidence. It can be also concluded both

Table 4 and Table 6 present that all conditions in the fixed platform have no air gap and cause wave load in deck.

The condition of the maximum wave crest height which is above the bottom of steel elevation of the lowest deck indicates that there is wave in deck issue.

Table 3. Comparison Between Bottom of Steel Elevation with Maximum Wave Crest Height from 90 Deg-Environmental Load at Maximum Water Depth

Maximum Wave Height at Collapse (m)	Bottom of Steel Elevation of The Lowest Deck (m)	Maximum Wave Crest Height above BOS Elevation (m)	Depth of Seabed Subsidence (m)
12.74	7.08	-0.70	0
11.74	6.08	-0.21	1
11.57	5.08	0.71	2
11.81	4.08	1.83	3
11.71	3.08	2.78	4
13.56	2.08	4.70	5
12.04	1.08	4.94	6
13.76	0.08	6.80	7

Table 4. Comparison Between Bottom of Steel Elevation with Maximum Wave Crest Height from 180 Deg-Environmental Load at Maximum Water Depth

Maximum Wave Height at Collapse (m)	Bottom of Steel Elevation of The Lowest Deck (m)	Maximum Wave Crest Height above BOS Elevation (m)	Depth of Seabed Subsidence (m)
17.17	7.08	1.51	0
16.55	6.08	2.20	1
15.90	5.08	2.87	2
15.95	4.08	3.90	3
15.87	3.08	4.86	4
15.62	2.08	5.73	5
16.00	1.08	6.92	6
16.27	0.08	8.06	7

Table 5. Comparison Between Bottom of Steel Elevation with Minimum Wave Crest Height from 90 Deg-Environmental Load at Minimum Water Depth

Maximum Wave Height at Collapse (m)	Bottom of Steel Elevation of The Lowest Deck (m)	Maximum Wave Crest Height above BOS Elevation (m)	Depth of Seabed Subsidence (m)
13.08	7.08	-0.54	0
13.23	6.08	0.54	1
12.59	5.08	1.22	2
12.90	4.08	2.37	3
12.01	3.08	2.93	4
12.20	2.08	4.03	5
12.80	1.08	5.33	6
12.46	0.08	6.15	7

Table 6. Comparison Between Bottom of Steel Elevation with Minimum Wave Crest Height from 180 Deg-Environmental Load at Minimum Water Depth

Maximum Wave Height at Collapse (m)	Bottom of Steel Elevation of The Lowest Deck (m)	Maximum Wave Crest Height above BOS Elevation (m)	Depth of Seabed Subsidence (m)
16.89	7.08	1.37	0
17.33	6.08	2.59	1
17.00	5.08	3.43	2
15.75	4.08	3.80	3
15.59	3.08	4.72	4
15.92	2.08	5.88	5
15.49	1.08	6.67	6
15.92	0.08	7.88	7

6.3. Wave Load in Deck

Wave load in deck is calculated using Eq. (1). The maximum wave height at collapse ($H_{Collapse}$) is added in calculation which taken from air gap analysis. The fixed platform condition is moderately equipped. The current velocity is taken from metaocean data. For kinematic wave factor, the condition is assumed as hurricane. Wave load in deck is computed using Stream Function's 7th wave theory. Table 7 until Table 10 present the detailed calculation by 100-year environmental load from 90^o and 180^o direction at both maximum and minimum water depth.

Both Table 7 and

Table 9 present that there are wave load in deck when the fixed platform is subsiding more than 0 m and 1 m by the condition of 100-year environmental load from 90^o direction. Table 7 shows that the minimum wave load in deck is 545.60 KN at the depth of subsidence of 2 m. Whereas

Table 9 depicts that the minimum wave load in deck is 82.40 KN at the depth of subsidence of 1 m.

The result which are shown in both Table 8 and Table 10 indicate that there are wave load in deck occured against the fixed platform by 100-year enviromental load from 180^o direction at no subsidence. It is found in Table 8 that the minimum wave load in deck is 843.14 KN at no subsidence. It is also observed in Table 10 that the minimum wave load in deck is 760.02 KN at no subsidence.

Table 7. Wave Load in Deck from 90 Deg-Environmental Load at Maximum Water Depth

Projected Area of Wave in Deck (m^2)	Fluid Horizontal Velocity (m/s)	Wave Load in Deck (KN)	Depth of Seabed Subsidence (m)
-	-	-	0
-	-	-	1
25.94	5.77	545.60	2
66.86	5.82	1432.74	3
102.59	5.73	2097.17	4
172.99	6.45	4624.65	5
180.84	5.77	3793.12	6
248.86	6.42	6638.15	7

Table 8. Wave Load in Deck from 180 Deg-Environmental Load at Maximum Water Depth

Projected Area of Wave in Deck (m^2)	Fluid Horizontal Velocity (m/s)	Wave Load in Deck (KN)	Depth of Seabed Subsidence (m)
18.38	8.15	843.14	0
26.84	7.86	1138.86	1
35.02	7.55	1360.90	2
47.51	7.50	1824.78	3
59.25	7.42	2218.74	4
69.91	7.26	2502.08	5
84.39	7.35	3099.11	6
98.23	7.40	3657.01	7

Table 9. Wave Load in Deck from 90 Deg-Environmental Load at Minimum Water Depth

Projected Area of Wave in Deck (m^2)	Fluid Horizontal Velocity (m/s)	Wave Load in Deck (KN)	Depth of Seabed Subsidence (m)
-	-	-	0
3.31	6.23	82.40	1
34.53	6.04	804.67	2
61.89	5.77	1299.56	3
98.47	5.72	2024.31	4
138.78	5.75	2893.34	5
206.42	6.41	5479.80	6
239.74	6.28	6090.88	7

Table 10. Wave Load in Deck from 180 Deg-Environmental Load at Minimum Water Depth

Projected Area of Wave in Deck (m^2)	Fluid Horizontal Velocity (m/s)	Wave Load in Deck (KN)	Depth of Seabed Subsidence (m)
16.67	8.13	760.02	0
31.55	8.22	1475.39	1
41.77	8.04	1860.78	2
46.30	7.50	1775.81	3
57.56	7.38	2133.18	4
71.75	7.45	2710.92	5
81.33	7.23	2878.06	6
96.13	7.33	3512.66	7

6.4. Reserve Strength Ratio with Wave Load in Deck

Pushover analysis is performed again by including wave load in deck to dertermine the updated reserve strength ratio. Figure 6 and Figure 8 capture the lowest updated reserve strength ratio which resulted by 100-year environmental load from 90° direction at both maximum and minimum water depth are 0.85 and 0.86 respectively. These occur in conditions when the fixed platform experienced seabed subsidence of 7 m.

Meanwhile, the highest updated reserve strength ratio which resulted from the current pushover analysis at both maximum and minimum water depth are 2.82 and 2.80 respectively. It is observed from Figure 7 and Figure 9 that these highest updated reserve strength ratio is resulted by 100-year environmental load from 180° direction.

It is also found that some updated reserve strength ratio does not meet the requirement criteria from API RP-2A WSD [6], which the minimum reserve strength ratio for manned evacuated of fixed platform is 1.60.

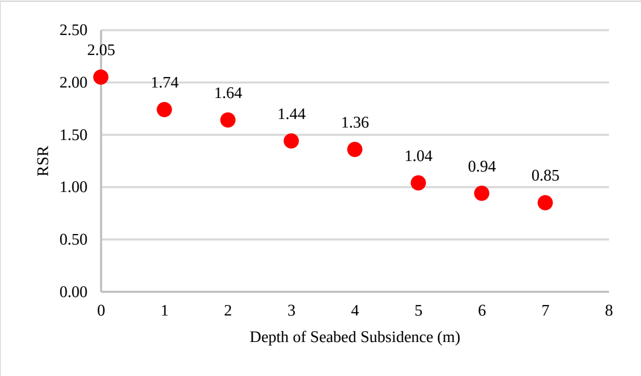

Figure 6. Reserve Strength Ratio of Fixed Platform with Wave Load in Deck from 90 Deg-Environmental Load at Maximum Water Depth

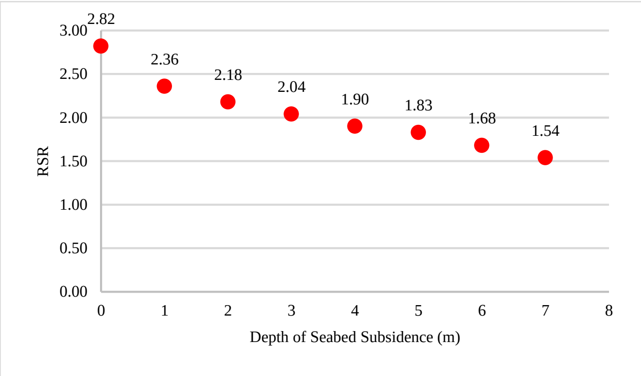

Figure 7. Reserve Strength Ratio of Fixed Platform with Wave Load in Deck from 180 Deg-Environmental Load at Maximum Water Depth

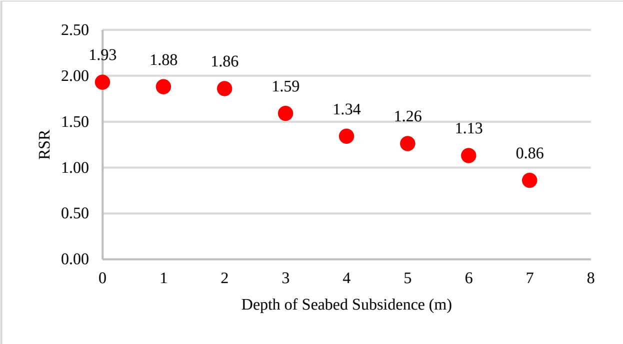

Figure 8. Reserve Strength Ratio of Fixed Platform with Wave Load in Deck from 90 Deg-Environmental Load at Minimum Water Depth

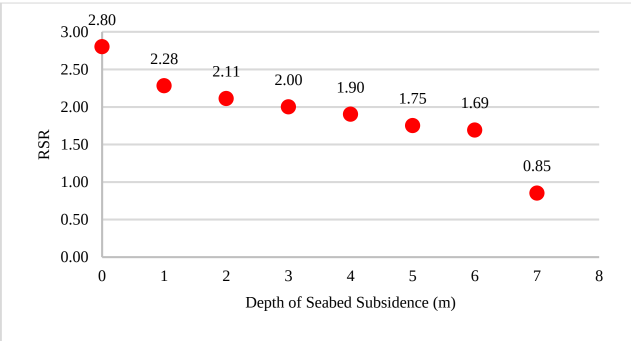

Figure 9. Reserve Strength Ratio of Fixed Platform with Wave Load in Deck from 180 Deg-Environmental Load at Minimum Water Depth

6.5. Probability of Failure

The probability of failure (P_f) is calculated using Monte Carlo simulation technique method which carried out by Matlab software. In this section, the probability of failure (P_f) results is presented in Figure 10 until Figure 13. These figures show that the probability of failure (P_f) increases with the increase of the depth of seabed subsidence.

If compared with the requirement of Marine Structural Design [14], Figure 10 indicates the probability of failure (P_f) does not meet requirement criteria when the fixed platform is subsiding more than 4 m at maximum water depth. Meanwhile, at minimum water depth, the fixed platform does not meet requirement criteria when it is subsiding more than 5 m. It is indicated in Figure 12.

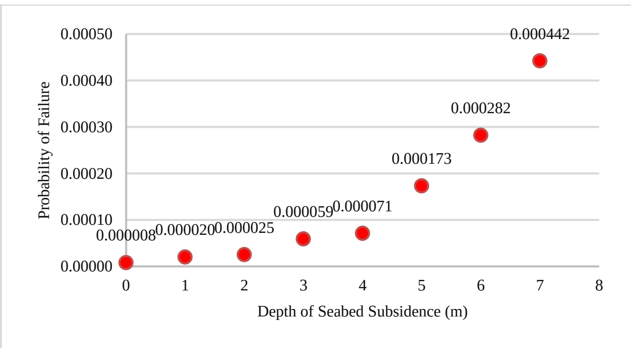

Figure 10. Probability of Failure of Fixed Platform from 90 Deg-Environmental Load at Maximum Water Depth

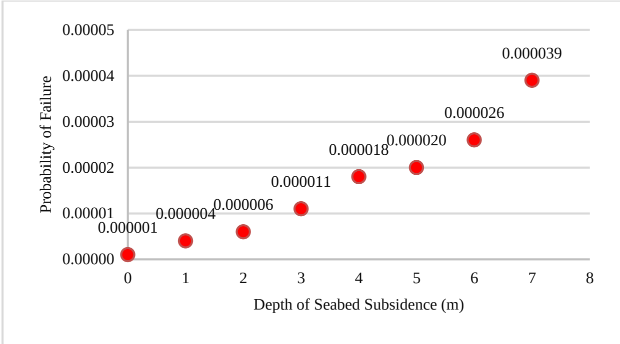

Figure 11. Probability of Failure of Fixed Platform from 180 Deg-Environmental Load at Maximum Water Depth

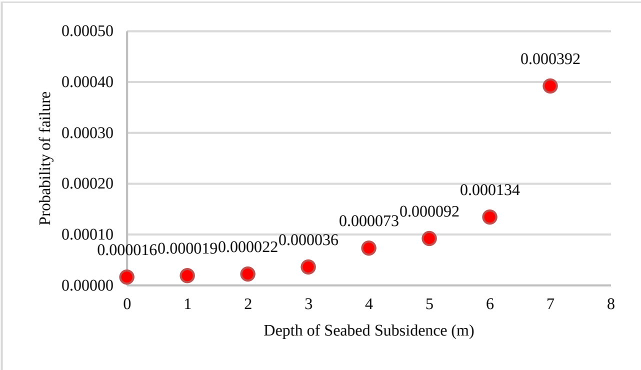

Figure 12. Probability of Failure of Fixed Platform from 90 Deg-Environmental Load at Minimum Water Depth

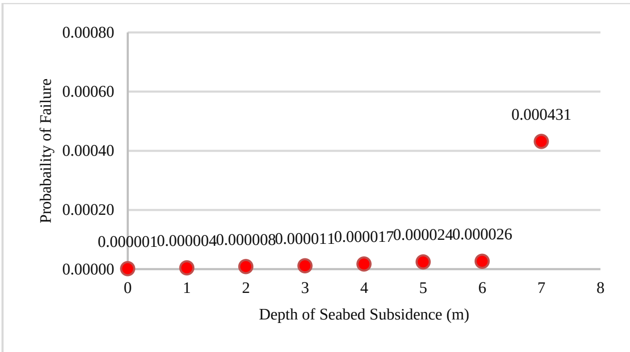

Figure 13. Probability of Failure of Fixed Platform from 180 Deg-Environmental Load at Minimum Water Depth

6.6. Reliability Index

The reliability index (β) is obtained by the probability of failure results which determined in Eq. (10). This process is performed in Matlab software. The reliability index (β) results are indicated in Figure 14 until Figure 17. As seen in these figures, the reliability index (β) decreases with the increase of the depth of seabed subsidence.

Both at maximum and minimum water depth, the highest reliability index which are resulted by 100-year environmental load from 180^{0} direction are 4.75. Those are shown in Figure 15 and Figure 17. Whereas Figure 14 and Figure 16 indicate that the lowest reliability index at both maximum and minimum water depth are 3.33 and 3.36 respectively. These occur when the fixed platform is subsiding about 7 m.

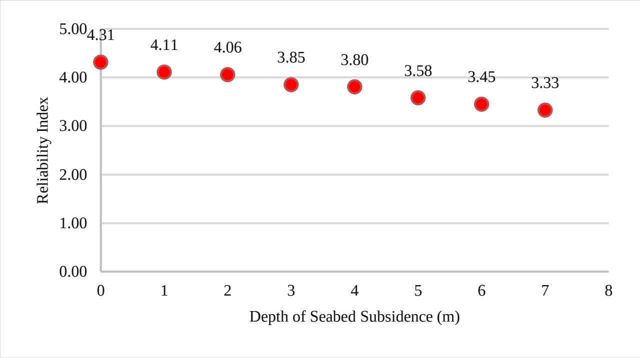

Figure 14. Reliability Index of Fixed Platform from 90 Deg-Environmental Load at Maximum Water Depth

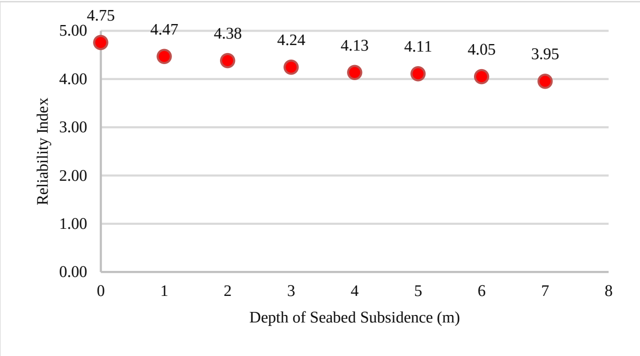

Figure 15. Reliability Index of Fixed Platform from 180 Deg-Environmental Load at Maximum Water Depth

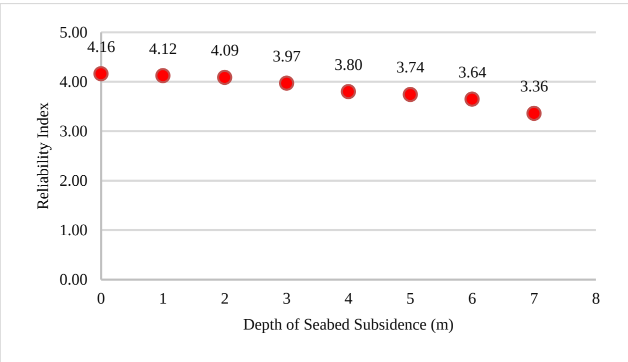

Figure 16. Reliability Index of Fixed Platform from 90 Deg-Environmental Load at Minimum Water Depth

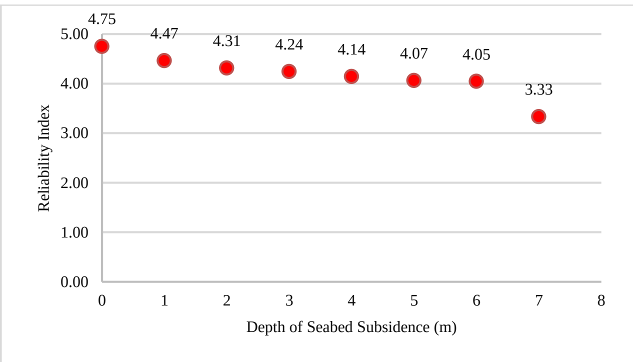

Figure 17. Reliability Index of Fixed Platform from 180 Deg-Environmental Load at Minimum Water Depth

6.7. Recommended Target Safety Level

In this study, the reliability index target is taken from Bai [21] which the target from high safety class is used as a reference. This reliability index target is 3.72.

If compared with the reliability index (β) that calculated in Section 6.6, the reliability index (β) of fixed platform is lower than the reliability index target when the structure is subsiding more than 4 m by 100-year environmental load from 90° and 270° at maximum water depth. Those are presented in Figure 19 and Figure 21. Whereas Figure 18 and Figure 20 indicate that the reliability index (β) of fixed platform is lower than the reliability index target when the structure is subsiding more than 5 m by 100-year environmental load from 65° and 245° direction at maximum water depth.

As can be seen in Figure 22 and Figure 25, the fixed platform has reliability index (β) which is lower than the reliability index target when the structure is subsiding more than 4 m at minimum water depth. These conditions occur when the structure is subjected to 100-year environmental load from 65° and 270° direction. Meanwhile, it is observed in Figure 23 that the reliability index (β) is lower than the reliability index target when the fixed platform is subsiding more than 5 m due to 100-year environmental load from 90° direction at minimum water depth.

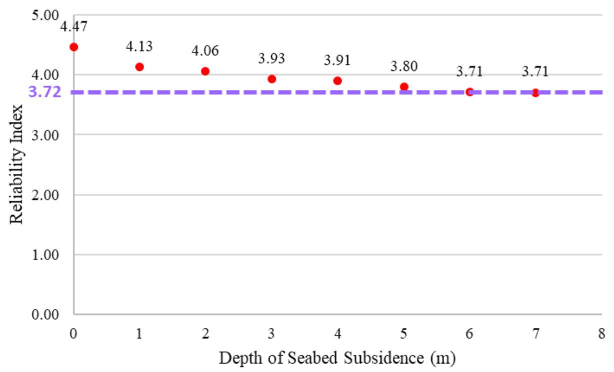

Figure 18. Recommended Target Safety of Fixed Platform from 65 Deg-Environmental Load at Maximum Water Depth

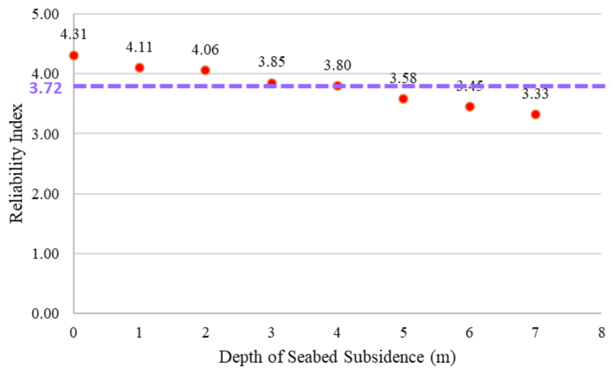

Figure 19. Recommended Target Safety of Fixed Platform from 90 Deg-Environmental Load at Maximum Water Depth

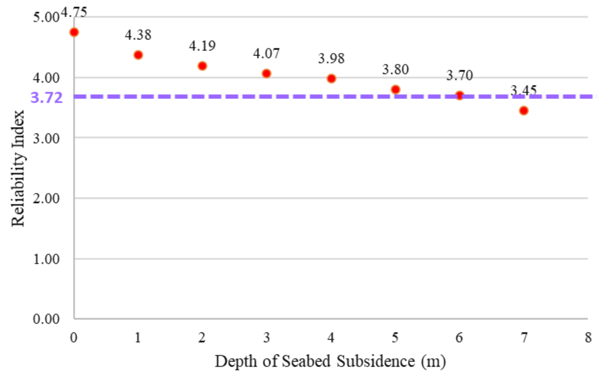

Figure 20. Recommended Target Safety of Fixed Platform from 245 Deg-Environmental Load at Maximum Water Depth

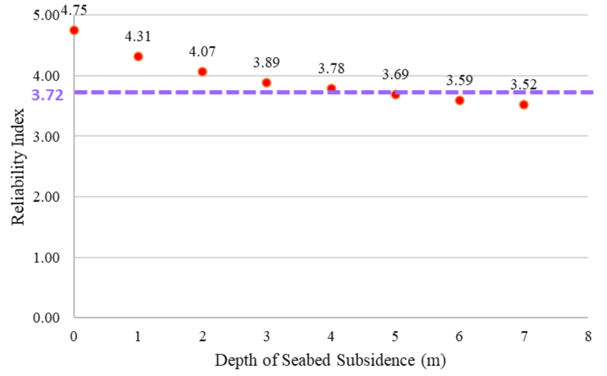

Figure 21. Recommended Target Safety of Fixed Platform from 270 Deg-Environmental Load at Maximum Water Depth

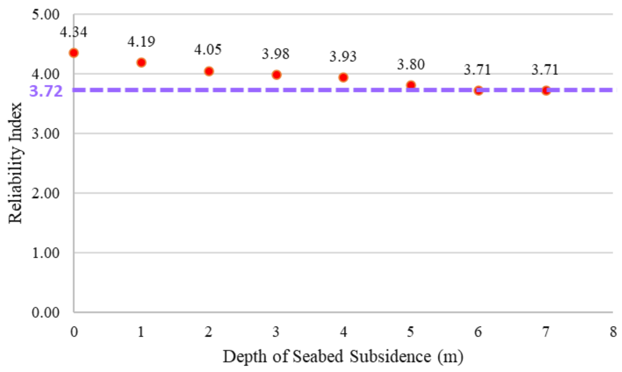

Figure 22. Recommended Target Safety of Fixed Platform from 65 Deg-Environmental Load at Minimum Water Depth

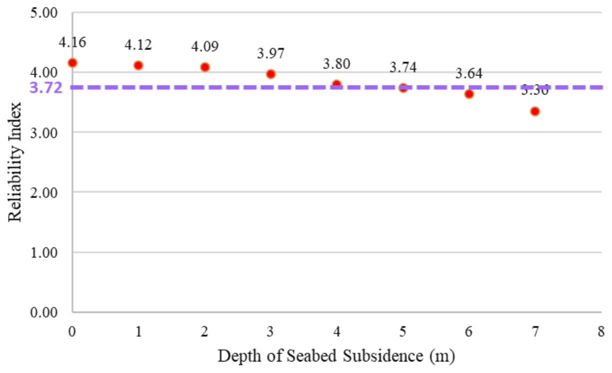

Figure 23. Recommended Target Safety of Fixed Platform from 90 Deg-Environmental Load at Minimum Water Depth

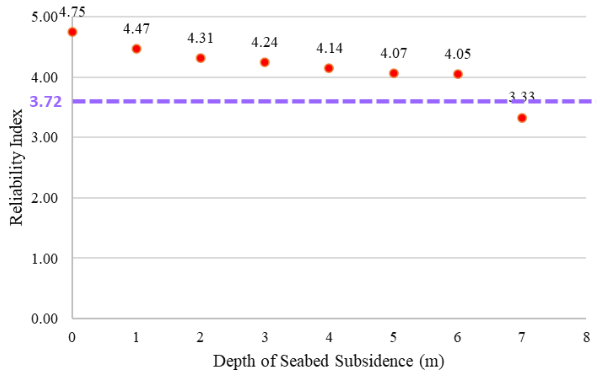

Figure 24. Recommended Target Safety of Fixed Platform from 180 Deg-Environmental Load at Minimum Water Depth

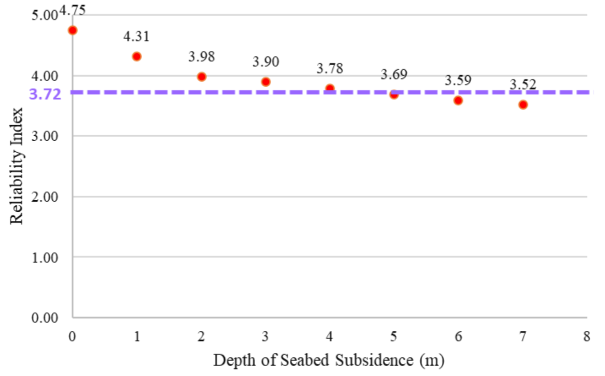

Figure 25. Recommended Target Safety of Fixed Platform from 270 Deg-Environmental Load at Minimum Water Depth

7. Conclusions and Recommendations

The following conclusions can be drawn from the results of the study.

- Pushover analysis is widely performed to calculate the reserve strength ratio of the fixed platform. The result of the reserve strength ratio without wave load in deck is detailed in Section 6.1. It is indicated that the lowest reserve strength ratio is 1.68, which means still meet requirement criteria of the minimum reserve strength ratio for manned evacuated of fixed platform from API RP-2A WSD [11].
- Air gap analysis is carried out based on the reserve strength ratio which resulted from pushover analysis. The analysis is required to determine whether the fixed platform is hit by wave in deck. By the results in Section 6.2, almost all conditions present that there is wave in deck. Therefore, it is necessary to rerun the pushover analysis with wave load in deck.
- Pushover analysis with wave load in deck is conducted to obtain the updated reserve strength ratio when the wave hit the deck. It is found from the results in Section 6.4 that the updated reserve strength ratio with wave load in deck is lower than the updated reserve strength ratio without wave load in deck. Higher reserve strength ratio due to the wave in deck can cause the bigger chance for the fixed platform will collapse. It is

crucial to include the wave load in deck analysis due to seabed subsidence in pushover analysis. Moreover, there are some conditions which present the updated reserve strength ratio are less than 1.0. These mean the structure may globally collapsed by wave height which is lower than 100-year maximum wave height (H_{100}) due to seabed subsidence and wave load in deck.

- Monte carlo simulation techniques method is adopted in reliability analysis. The results are presented in Section 6.6. Both the highest and lowest reliability index (β) which resulted from calculation are 4.75 and 3.33 respectively. However, some reliability indexes are lower than the target of high safety class which referred to Bai [21].
- The pushover and reliability analysis are carried out by including environmental load in eight directions. The analysis results which are shown in this paper are only the highest and lowest results obtained from the different directions of environmental load on the total load combinations. The highest result comes from the 180$^{\mathrm{o}}$ environmental load. Whereas the lowest result comes from the 90$^{\mathrm{o}}$ environmental load. The total load of the fixed platform is gained from the dead load, live load and environmental load in each direction. The uncertainties of environmental conditions which are represented by wave height and wave period indicate the contributions of environmental load directions both in the jacket and deck to the whole fixed platform's strength and reliability.

By the results which given in this study, the following recommendations can be further conducted in the future.

- The method which is used to calculate wave load in deck may be further studied by considering the type and geometry of the fixed platform. There are other methods to calculate wave load in deck such as component method, CFD method, morison equation method and diffraction method.
- In this study, the wave load in deck is focused on horizontal wave load in deck. It would be better if the vertical wave load in deck is also considered in pushover analysis.
- The structural analysis which carried out in current study is static non-linier pushover. It is recommended to perform dynamic analysis by including wave load in deck.
- Reliability analysis is performed by Monte Carlo simulation technique method. There are other methods to calculate probability of failure (P_f) and reliability index (β). The reliability analysis can be performed in some methods which those results then compared each other.

List of Symbols

LD_{EL}	Bottom of steel of lowest deck
A_{deck}	Projected area of wave in deck
A_{deckx}	Projected area of wave in deck in X-axis
A_{decky}	Projected area of wave in deck in Y-axis
C_D	Drag coefficient
E_{100}	Base shear of 100-year environmetal load
$E_{collapse}$	Base shear of fixed platform at collapse
E_i	Base shear of fixed platform
F_{Deck}	Wave load in deck
H_{100}	100-year maximum wave height
$H_{Collapse}$	Wave height of fixed platform at collapse
H_s	100-year significant wave height
H_i	Random wave height
P_f	Probability of failure
R	Resistance / capacity of the structure
S	Load on the structure
T_i	Random wave period
T_p	100-year peak period
U	Current velocity in line with wave
V	Fluid horizontal velocity
Z	Performance function
α	Metaocean constant
α_{cb}	Current blockage factor
α_{wk}	Wave kinematic factor
β	Reliability index
θ_w	Wave direction
ρ	Seawater density

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