Development of Risk-Reliability Based Underwater Inspection for Fixed Offshore Platforms in Indonesia

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Abstract. In RBUI method, platform with higher risk level will need inspection done more intensively than those with lower risk level. However, the probability of failure (PoF) evaluation in RBUI method is usually carried out in semi quantitative way by comparing failure parameters associated with the same damage mechanism between a group of platforms located in the same area. Therefore, RBUI will not be effective for platforms spread in distant areas where failure parameter associated with the same damage mechanism may not be the same. The existing standard, American Petroleum Institute, Recommended Practice for Structural Integrity Management of Fixed Offshore Structures (API RP-2SIM), is limited on the general instructions in determining the risk value of a platform, yet it does not provide a detail instruction on how determining the Probability of Failure (PoF) of platform. In this paper, the PoF is determined quantitatively by calculating structural reliability index based on structural collapse failure mode, thus the method in determining the inspection schedule is called Risk-Reliability Based Underwater Inspection (RReBUI). Models of 3-legs jacket fixed offshore platform in Java Sea and 4-legs jacket fixed offshore platform in Natuna Sea are used to study the implementation of RReBUI.

1 Introduction

Risk Based Underwater Inspection (RBUI) method has been developed and implemented in offshore platform inspection in Indonesia [1]. Previously, the inspection of offshore platform used Time Based Inspection (TBI) system in accordance to Indonesian government regulations since 1977. TBI is conducted regularly based on the types of inspection. Minor inspection is carried out annually, while major inspection was carried out once for 2 years, and complete inspection was carried out once for four years [2]. Due to the development of technology and demand in efficiency, Indonesian government encourages application of RBUI method as an alternative of TBI in determining inspection interval. By RBUI method, platform with higher risk level will need more often inspection than those with lower risk level.

Existing standard API RP-2SIM has not discussed the detail of risk determination, such as determining Probability of Failure (PoF), and Consequence of Failure (CoF). In previous RBUI, PoF evaluation is usually conducted in semi quantitative way by comparing failure parameters associated with the same failure mechanism between some platforms in the same area. However, RBUI method will not be efficient to be conducted for platforms spread in distant areas where failure parameters associated with the same damage mechanism may not be the same. Therefore, the risk estimation should be conducted quantitatively based on the same failure mode.

In this paper, Risk-Reliability Based Underwater Inspection (RReBUI) is developed, where the PoF is determined quantitatively by calculating structure reliability index based on collapse failure mechanism in which uncertainty of wave load and structural resistance are considered. Meanwhile, CoF factor calculated quantitatively in accordance to API RP-2SIM. By using RReBUI method, risk on every platform can be determined quantitatively without comparing failure parameter based on expert justification.

For case studies, 2 (two) offshore platform models installed in Java Sea (Indramayu offshore, West Java Province) and West Natuna sea (Anambas Islands, Riau Islands Province) are used as case study. Figure 1 shows the models of offshore platform.

2 Methodology

RReBUI analysis is started by collecting structure data in form of drawing and basis design. This structure data is then used to create model in SACS software for further analysis. Wave data is also collected, which has significant wave height parameter (H_s), wave period (T_n), and also maximum wave height (H_{max}).

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Fig. 1. Offshore platform 1: Java Sea (left) and Offshore platform 2: Natuna Sea (right)

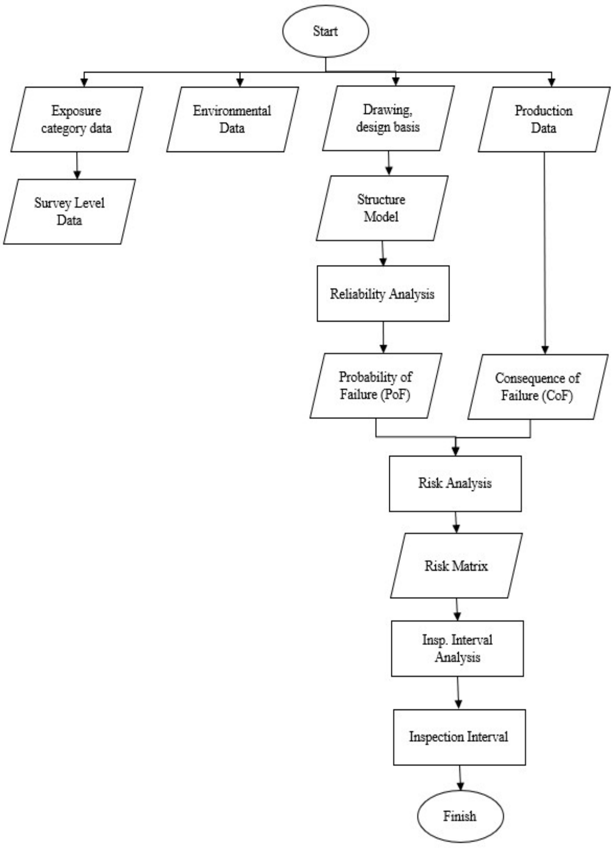

Fig. 2. Research Flow Chart

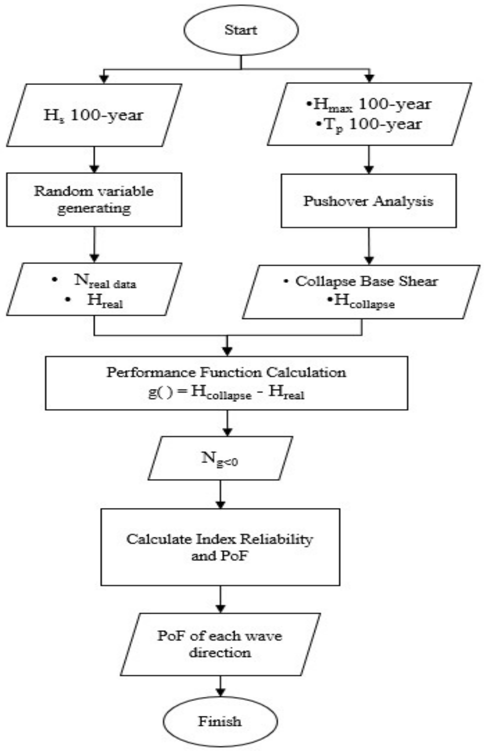

Fig. 3. Flow chart of index reliability and PoF calculation

Figure 2 and Figure 3 show research and probability of failure (PoF) calculation, respectively.In this research, the reliability analysis is divided into two stages; the random wave data analysis and collapse analysis

2.1 Random wave data analysis

One of loads to be concerned in structure analysis is load affected by the environment, in which an offshore structure is operated. Environmental load applied in this design is wind, current, and wave load.

The loading in structure is predicted as the function of some variables, such as wave height, wave period, wind speed, wind direction, and current [3].

The data of wave height and period can be obtained from these following results:

a. Direct observation by using wave recorder in the observed location
b. Visual observation of vessel passing certain coordinate
c. Observation of water surface using altimetry system
d. Prediction of wave and wind data in certain location

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The wind data can be obtained from Indonesian Agency for Meteorology, Climatology, and Geophysics, and National Oceanic and Atmospheric Administration, while the current data at platform locations can be calculated by using numerical modeling. Generally, wave load is the most affecting load to the structures.

For structural reliability calculation based on collapse failure mode, we need wave data for return periods 1 year, 10 years and 100 years. Those data can be calculated using long term wave data analysis. The wave distribution in long term period can be approached using continuous distribution from Weibull. The linear formula of the probability density function (PDF) is given in this following formula:

$$\ln\left[\ln\left\{\frac{1}{1-P(H)}\right\}\right] = \xi\ln(x) - \xi\ln(\lambda) \tag{1}$$

P(H) = probability of wave existed
– = form parameter with common value is between 0,75 to 2,0; Whereas for ocean wave, the value is ranged between 0,9 t o. 1,1 (Naess: 0,7 to 1,3) 18
λ = scale parameter whose value is depend on extreme value of variable x; while for the ocean wave, the high extreme value occurs once in some period of time (m)
x = object/intensity parameter observed, for instance height wave, hence $x = H$

Weibull distribution can be approximated with linear curve if variable x in the right side of the above equation is replaced with *(H – a).* Variable here is threshold wave height, which is the smallest wave height in the ocean. For closed water, *a* may have very small value (≈0), while for open water, it may have value between 0,5 to 2,0 m. Weibull distribution curve will be linear if it is drawn on the graphic correlating *ln{ln[1/1-P(H)]}* as ordinat and *ln(H –a)* as abcissa. The wave height used is significant wave height (H_S), if the wave known is maximum wave height (H_{max}), so H_S can be defined as:

$$H_S = H_{max}/1.86 \tag{2}$$

Beside Weibull, random wave distribution can be approached using Rayleigh distribution,

$$f_x(x) = \frac{2x}{R}\exp\left(-\frac{x^2}{R}\right),\ x \geq 0 \text{ with } R = \frac{1}{n}\sum_{i=1}^{n} x_i^2 \tag{3}$$

If the lower limit of one per three of the biggest height is noted as x*, the probability value of wave height occurrence exceed x* is 1/3 as seen in this equation:

$$\Pr\{X \geq x_*\} = \int_{x_*}^{\infty}\frac{2x}{R}\exp\left(-\frac{x^2}{R}\right)dx = \frac{1}{3} \tag{4}$$

From equation (4), the lower limit value, x_* can be a deritative into function of parameter in this equation below:

$$x_* = \ln(3)\sqrt{R} = 1.048\sqrt{R} \tag{5}$$

H_s in PDF can be observed in Figure 4. Thus we can see that Hs is the central point of area under the PDF curve with lower limit of x_*.

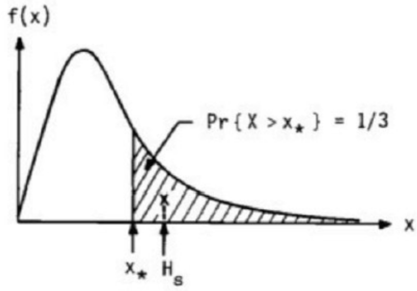

Fig. 4. Definition of significant wave height (H_s) in a PDF curve (Ochi, 1998)

In order to find out the central points of area under PDF curve, we can calculate it using this following formula.

$$H_s = x_{1/3} = \frac{\int_{x_*}^{\infty} x\cdot f_x(x)dx}{\int_{x_*}^{\infty} f_x(x)dx} = \frac{x_*\cdot\exp\left(-\frac{x_*^2}{R}\right)+\sqrt{\pi R}\left\{1-\Phi\left(\sqrt{\frac{2}{R}}x_*\right)\right\}}{1/3} \tag{6}$$

With substitution of 2 (two) above equations, the value of H_s can be calculated as follows.

$$H_s = \left[\sqrt{\ln(3)} + 3\sqrt{\pi}\left\{1-\Phi\left(\sqrt{2\ln(3)}\right)\right\}\right]\sqrt{R} \tag{7}$$

$$H_S \sim 1.42\sqrt{R} \tag{8}$$

2.2 Reliability analysis

In engineering design, uncertainties in structural analysis may exist in loading, material properties, geometry, and surface condition. These uncertainties must be taken carefully to ensure that the design can perform its intended function with desired confidence that failure will be avoided. The traditional way of dealing with uncertainties is by using safety factors which set conservative limits for the design values of factors such as stress that are derived from uncertain design parameters.

Reliability analysis of structure is used to evaluate failure of structure related to force-load system probability. The information of average and uncertainty variable distribution defines structure failure probability. Structure reliability design model can define load and resistance as random variable probability. Figure 5 shows that reliability equations depend on the intersecting area of probability density function between load and resistance. As in Figure 5, it can also be stated that there are no area which has no risk.

In general, failure function is defined as

M = *g(R,S)* = *R – S* (9)
M = *g(R,S)* = Performance function
R = resistance function
S = Load Functions

Probability of failure can be defined as

$$P_f = P(R < S) \tag{10}$$

The reliability index can be calculated as

$$\beta = \frac{\mu_M}{\sigma_M} \tag{11}$$

μ_M= average *M* (safety margin)

$\sigma_M =$ standard deviations M (safety margin)

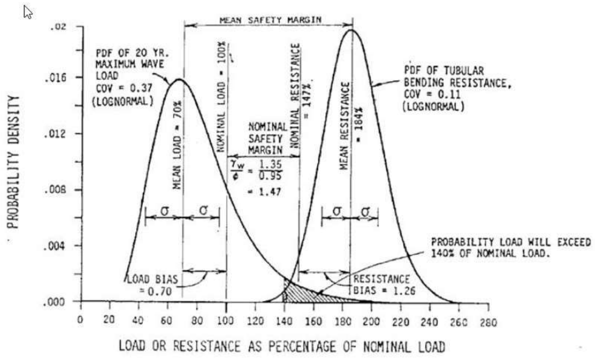

Fig. 5. Probability density function of structure failure [4]

Reliability analysis can be started by determining performance function that defines the parameter of structure failure mode. Structure failure mode can be defined based on pushover [5], joint fatigue [6], fracture mechanics [7] and structural member failure.

The reliability analysis is started by determining the performance function which defines the failure parameter of the structure. Random wave data analysis is an analysis of individual wave data to generate random waves with return period of 1000 years in order to obtain random wave data which is predicted to be structure load. This data-generating produces 100 million data of random wave height that will be used as wave data input to calculate the forces acting on the structure. Pushover analysis is carried out using SACS software, by increasing the wave load incrementally. The simulation is done until the structure collapses and then the relation between the wave height and the load that makes the structure collapses is obtained. These both analyses (random wave analysis and pushover analysis) are combined so the numbers of wave data concurrence that make the structure collapse is obtained. This number is compared to the number of total wave that occurrences, so the value of probability of failure (PoF) is obtained. This PoF value will be used later in RReBUI analysis.

RReBUI analysis is started by calculating the platform risk matrix by x- axis parameter as PoF and y-axis as CoF. The PoF value has been defined by using reliability analysis. Meanwhile, CoF analysis is determined qualitatively based on API RP-2SIM standard, thus we can obtain point in range 1-5 based on the level of failure consequence severity. The combination of PoF and CoF value result to platform risk value in risk matrix. API RP-2SIM provides conversion method and risk matrix that are obtained into an inspection interval. This conversion method uses exposure category factor and inspection level classification. The result of this inspection interval is then classified into inspection interval for each inspection level that ranges from 1 to 4. Each of this inspection level has different detail examination structure, with different interval schedule.

3 Results and discussions

Reliability analysis is started in determining performance function which is used as the parameter of structure failure. Parameter of structure failure used is as follows.

$$RSR > RSRmin$$

$$\frac{ultimatelateralload}{100yearswaveload} > RSRmin$$

$$\frac{collapsebaseshear}{initialbaseshear} > RSRmin$$

$$collapsebaseshear > (RSRmin)initialbaseshear$$

$$H_{(collapse)} > (RSRmin)H_{(initial)}$$

$$(RSRmin)H_{(initial)} - H_{(collapse)} < 0$$

In addition, the performance function is,

$$g = Resistance?\,Load$$

$$g = maxallowablebaseshear - realbaseshear$$

$$g = collapsebaseshear - baseshearH_{(real)}$$

$$g = H_{(collapse)} - (RSRmin)H_{(real)}$$

The analysis of random wave results to the value of wave maximum height with return period 1000 years. In addition, pushover analysis results to the value of wave height affecting toward the collapse structure. The results of these both analyses are described in Figure 6 below.

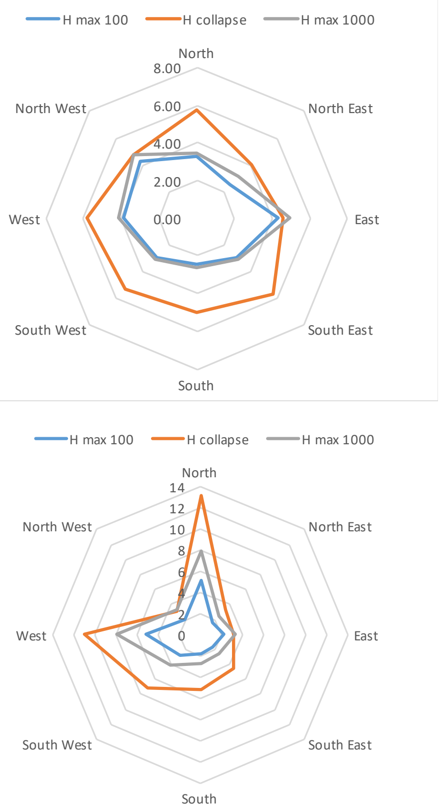

Fig. 6. Comparison of the the H_{max} 100-year, $H_{collapse}$, and H_{max} 1000-year values in Platform 1 (top) Java Sea and Platform 2 (bottom) Natuna Sea

The Probability of Failure is then calculated based on the data of 100 milion results from the analysis value above by using Matlab software and by comparing each score of Hcollapse and Hmax 1000 year based on the performance function. Negative performance function means that the structure is failed. Then, the total of negative value is calculated and compared to 100 million wave data. This value then is called as the Probability of Failure (PoF) presented in Table 1 below.

Table 1. Calculation of PoF value

Direction	Platform 1: Java Sea		Platform 2: Natuna Sea	
	N fail	PoF	N fail	PoF
Omni	16130	1.61.E-04	580434	5.80.E-03
North	0	0.00.E+00	26364	2.64.E-04
North East	0	0.00.E+00	616570	6.17.E-03
East	34816	3.48.E-04	746055	7.46.E-03
South East	0	0.00.E+00	4293	4.29.E-05
South	0	0.00.E+00	1581	1.58.E-05
South West	0	0.00.E+00	13452	1.35.E-04
West	8	8.00.E-08	300665	3.01.E-03
North West	16282	1.63.E-04	531329	5.31.E-03
Maximum	**34816**	**3.48.E-04**	**746055**	**7.46.E-03**

The PoF value obtained is then converted into reliability index value [8] as presented in Table 2a and Table 2b

Table 2a. Conversion of PoF value into reliability index

Platform	Direction	PoF	Reliability(β)
Java Sea	East	3.48.E-04	3.26
Natuna Sea	East	7.46.E-03	2.87

Table 2b. Conversion of PoF value into reliability index

Safety Class	Target (PoF)	Reliability Index (β)
Low	0.01	2.32
Normal	0.001	3.09
High	0.0001	3.72

For CoF calculation, additional information is needed related to the determination of failure consequence in accordance to API RP 2-SIM [9] which is the parameter from the safety, environment, and business point of view. Table of additional information is shown on this Table 3 below.

Table 3. Data and information needed in RReBUI analysis

	Java Sea	Natuna Sea
Reliability Index	3.2636	2.8728
Platform Crew	Unmanned	Manned
Oil Production (bpd)	4200	1050
Gas Production (mmscfd)	55.8	105.2
Platform Price (million USD)	<100	100 - 300

The calculated CoF and PoF parameters are then used to analyse the severity level in range 1-5. Table of parameter CoF and PoF categories, and the classification of risk matrix severity level is shown in Table 4 and Table 5.

Based on API RP 2SIM, the consequence criteria were divided into three levels as described in Table 6. These levels determined the inspection interval as stated in API RP2A-WSD and API RP 2SIM.

Table 4. Parameter of PoF, CoF, and classification of severity level

Parameter	Factor	Score				
		1	2	3	4	5
CoF	Safety	Unmanned	-	-	-	Manned
	Bussiness (oil and gas production)	Production < 2500 BOEPD	Production 2501 – 5000 BOEPD	Production 5000 – 7500 BOEPD	Production 7501 – 10000 BOEPD	Production > 10000 BOEPD
		Platform Price <$100 MM	-	Platform Price $100 -300 MM		Platform Price <$100 MM
	Environment (oil production)	Production < 2500 BOPD	Production 2501 – 5000 BOPD	Production 5000 - 7500 BOPD	Production 7501 – 10000 BOPD	Production > 10000 BOPD
PoF	**Reliability Index**	**>4.44**	**3.72-4.44**	**3.09-3.72**	**2.32-3.09**	**<2.32**

Table 5. Calculation result of PoF and CoF

Platform	Data					CoF				PoF
	(β)	Platform Crew	Oil Production (bpd)	Gas Production (mmcfd)	Platform Price	Safety	Business	Environment	CoF Value	PoF Value
Java Sea	3.26	Unmanned	4200	55.8	< 100	1	2	2	2	3
Natuna Sea	2.87	Manned	1050	105.2	100 - 300	5	3	1	5	4

Table 6. Exposure level-based inspection program recommended by API

Exposure Category Level	Survey Level (Years)			
	I	II	III	IV
L-1	1	3–5	6–10	
L-2	1	5–10	11–15	Case by Case only
L-3	1	5–10	Case by Case only	

The calculated CoF and PoF are then used to determined platform's exposure category and platform positions in risk matrix as shown in Table 7 and Table 8 below

Table 7. Exposure Categories of Platforms

No	Platform Location	PoF	CoF	Risk	Exposure Category
1	Java Sea	3	2	Medium	L3
2	Natuna Sea	4	5	High	L1

Table 8. Platform positions in risk matrix

Consequence of Failure					
5				Platform 2	
4					
3					
2			Platform 1		
1					
	1	2	3	4	5
	Probability of Failure				

Inspection intervals are then determined in accordance to API RP-2SIM and the result is shown in Table 9 below.

Based on Table 9, it is clearly seen that the value difference resulted by each analysis of different platforms. Factor of platform characteristic, wave force, and information related to safety, environment, and business become the important points of the risk and inspection interval difference.

4 Conclusion

Reliability index value can be used for Probability of Failure (PoF) calculation in RReBUI analysis. By using RReBUI method, risk comparison of 2 (two) platforms located in distance areas can be determined quantitatively without comparing failure parameter based on expert justification. The results of RReBUI analysis for 2 (two) fixed offshore platform models is an inspection plan that accentuated safety, but also had a longer interval when compared with the previous time-based methods. It means, the efficiency objectives of inspection operation could be accomplished.

Table 9. Calculation result of inspection interval

Platform	PoF	CoF	Risk	Exposure Category	Inspection Interval			Last Inspection		Next Inspection		
					Level 1	Level 2	Level 3	Level 1	Level 2	Level 1	Level 2	Level 3
Java Sea	3	2	Medium	L3	1	9	*	2016	2015	2017	2024	*
Natuna Sea	4	5	High	L1	1	3	6	2016	2015	2017	2018	2021

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