International Journal of Marine Engineering Innovation and Research, Vol. 9(2), June. 2024. 387-394
(pISSN: 2541-5972, eISSN: 2548-1479)

Reliability of Jacket-Type Structure Considering the Reserve Strength Ratio (RSR)

Brigitta V. E. Tito[1], Rudi W. Prastianto [2], Daniel M. Rosyid [3]

(Received: 15 June 2024 / Revised: 19 June 2024 /Accepted: 26 June 2024)

***Abstract*— The projected demand for energy globally will continue to rise by 45% by 2030, with an average growth rate of about 1.6% per year. Oil and gas are estimated to fulfil about 80% of the world's energy needs. One facility that supports oil and gas exploitation is an offshore structure of the jacket-type platform. The challenge in building a jacket platform is the reliability of the structure. Offshore structures are designed to withstand extreme wave loads that can cause the collapse of individual components or the entire structure. This paper aims to analyze the reliability of the structure with the ultimate limit state. The author performs an ultimate strength analysis using the Nonlinear Pushover Analysis method to obtain the Reserve Strength Ratio (RSR) and a reliability analysis using the Monte Carlo Simulation (MCS) method. This analysis shows that the RSR minimum of 9.33 occurs with a 135° loading direction. The MCS results show that the Jacket platform has a high level of reliability of 0.99997, which fulfils the minimum required reliability for offshore structures.**

Keywords— Monte-Carlo Simulation (MCS), nonlinear analysis, offshore structure, pushover analysis, Reserve Strength Ratio (RSR).

I. INTRODUCTION

Energy demand has continued to increase significantly in recent years recent years. It is predicted that by 2030, annual global energy demand will increase by an average of around 1.6%. Oil and gas (oil and gas) will be an essential sector that cannot be abandoned in the next few years. Indonesia itself projects its fuel oil demand to reach needs to reach around 1.76 million Barrels Oil Per Day (BOPD) in 2025 and continue to increase until 2050 [1]. Infrastructure needs to support oil and gas needs to be a necessity that will continue to grow, especially for offshore areas.

Jacket structures dominate Indonesia's oil and gas infrastructure because they are suitable for shallow to medium water depths and are economical in cost [2]. Operations are conducted in shallow waters at 0 - 400 meters. A jacket structure is a structure made of tubular steel. It usually has three, four, six, or eight legs that transmit environmental and topside loads to the transmit environmental loads and topside loads to piles installed on the seabed [3]. The design stage is the biggest expense in oil and gas field development. Therefore, in designing the structure, the cost represented by the construction weight must be minimized and adjusted based on its operating function [4]. Another challenge is the extreme and random marine environment. The reliability of the structure is important to maintain operations on the platform [5].

Reliability is an important factor in jacket structure design. The design of the jacket structure cannot escape the assessment of its structural strength. The jacket structure is designed to withstand loads that can cause the collapse of individual components or the entire structure. If a part fails, the structure still has a Reserve Strength Ratio (RSR) or the ability to withstand its ultimate load [6].

Nonlinear pushover analysis can perform structural integrity design by modeling the geometry, load application, and foundation using SACS software. This study performs full plastic nonlinear pushover analysis in a wave-current environment to assess the structural responses of a three-legged, minimalist jacket-type offshore structure. SACS is used in this analysis for global modeling, applied load, and the interaction of pile and soil.

A. Jacket Offshore Platform

Jacket platforms, also known as template-type structures, are composed of a welded jacket or space frame that serves as lateral reinforcement for the piles and facilitates pile driving. The platform legs brace the piles and guide the driving piles, giving the structure its name. The jacket is securely anchored to the ocean floor and is designed to withstand wave loads. The platform consists of superstructures or topsides with decks for various operational activities. It is primarily designed for production purposes and is suitable for depths up to 400 meters [3], [7].

According to [7], jacket platforms have several advantages, such as their ability to withstand large deck loads, ease of construction and transportation, suitability for large oil fields and long-term production, and good stability provided by using piles in the foundation. Nevertheless, there are also disadvantages for this platform, such as costs that rise exponentially as the water depth increases, the high installation and upkeep costs, the inability to reuse the structure, and the susceptibility to

Brigitta V. E. Tito is with Departement of Ocean Engineering Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: brigittaviolyna322@gmail.com

Rudi W. Prastianto is with Departement of Ocean Engineering Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: rudiwp@oe.its.ac.id

Daniel M. Rosyid is with Departement of Ocean Engineering Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia. E-mail: dmrosyid@oe.its.ac.id

material degradation caused by corrosion of the steel structural components.

In this research, the author conducts the pushover analysis to obtain the structure's reserve strength ratio (RSR) by gradually increasing the environmental load of extreme conditions until the structure collapses due to the formation of plastic members. Plastic members will be used in reliability analysis, and each member's probability of failure will be used for system reliability calculations.

B. Nonlinear Pushover Analysis

Prediction of reserve strength capacity is immediately useful for extreme environmental conditions (100-year return period) in jacket structural response. The structural elements are assumed to be rigidly connected while the analysis is conducted. Full plastic pushover analysis can be done to determine the ultimate strength of the platform, according to API RP2A LRFD [8]. Lloyd [9] discusses the sources of the frame behavior's reserve and residual strength.

According to recent research, static pushover analysis is typically adequate to illustrate how resistant the structure is to extreme environmental loads. An analytical tool is used to perform the integrity assessment under extreme loading scenarios to obtain the system reserves strength that goes beyond the capacities of individual components failing. Reserve strength is defined as the ability of the structure to withstand loads over its design value. RSR can be calculated as below [10].

$$RSR = \frac{R_{ult}}{R_{initial}} \quad (1)$$

Where R_{ult} is the structural response at ultimate strength, and $R_{initial}$ is the structural response initial condition (design strength).

In a fixed offshore structure, loads are distributed by a network of pathways. Therefore, the collapse of one individual component does not fail the platform's overall structure.

Reserve strength is assessed by subjecting the structure to the highest possible loads caused by extreme environmental and conducting a static pushover analysis. Static pushover analysis involves applying a vertical load followed by a horizontal load (wave loading) on the structure. The load is increased gradually until the structure collapses. The applied load gradually increases during incremental loading, causing the structure to transition into an elastoplastic range. As a result, the members of the structure start to yield, leading to a decrease in stiffness and the production of permanent plastic deformations. When subjected to cyclic load, the structure experiences repeated yielding, resulting in a gradual collapse.

C. Reliability Analysis

Reliability in structural reliability systems can be shown as a problem between demand (load) and capacity (power). It is traditionally based on an appropriate safety factor [11]. The conventional measure of safety factor (Z) is the ratio between the assumed capacity (X) and load (Y) following the equation below:

$$Z = \frac{X}{Y} \quad (2)$$

The probability of failure measures the inability of a system to meet capacity and can be related to the part of the safety factor distribution whose value is less than one, given the following equation:

$$P_f = P[Z \leq 1] = F_z(1) \quad (3)$$

Where F_z is the cumulative distribution function of Z, in other words, the probability of the system not failing or reliable (K) is:

$$K = 1 - P_f = P[Z > 1] = 1 - F_z(1) \quad (4)$$

When the joint probability distributions of X and Y are known, system reliability can be calculated based on the cumulative distribution function of X⁄Y.

II. METHOD

The focus of this research includes investigating a novel fixed offshore wellhead platform to mitigate the challenges associated with offshore structure collapse analysis through the widely utilized SACS software. The structure's Reserve Strength Ratio (RSR) was assessed by a collapse analysis of the jacket platform with three legs. Employing software as the interface takes less time to assess complicated offshore structures.

A. Jacket Structure Data

This study will analyze a minimal jacket-type platform in the Madura Field at a depth of 262 feet. The coordinate location of this platform is 114°18'21" E dan 7°18'45" S. This structure is a three-legged jacket platform and weighted around 4030 kips. The structural data utilized in this investigation is presented in Table 1. The isometric

TABLE 1.
PLATFORM'S STRUCTURAL DATA

Description	Appurtenance
Structure type	Wellhead platform
Number of Decks	3
Number of Legs	3
Number of Piles	9 skirt pile
Number of Structure Elevation	8

International Journal of Marine Engineering Innovation and Research, Vol. 9(2), June. 2024. 387-394
(pISSN: 2541-5972, eISSN: 2548-1479)

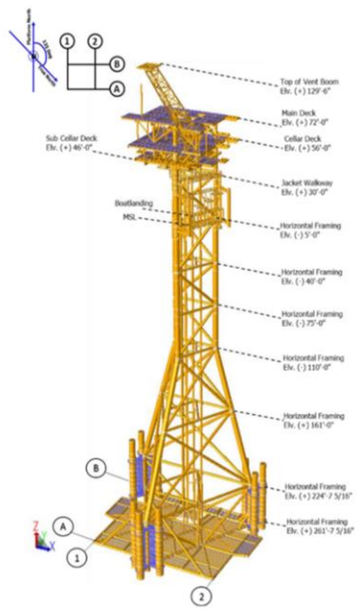

Figure. 1. Isometric view of the structure

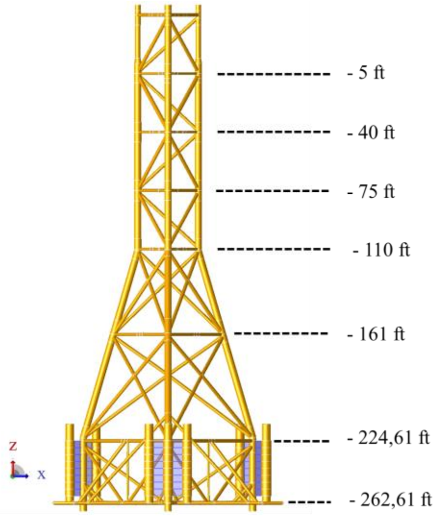

Figure. 2. Elevation of the structure

view of the structure and elevation of the structure is shown in Figure 1 and Figure 2.

B. Environmental Data

Environmental conditions at the site consist of operating conditions (1-year return period) and extreme conditions (100-year return period), the environmental data of which can be seen in Table 2 and Table 3.

1) Wave Data
   The wave loads used in the in-place static analysis are presented in Table 2. Wave load data consists of 16 wave directions and the wave height and period.
2) Current Data
   The current loads used in the in-place static analysis are presented in Table 3. Current load data consists of 16 directions of current speed.
3) Soil Data
   Soil data will affect the capacity of the pile to support the structure in remaining standing. The following soil data is used in the pile-soil interaction analysis, which consists of axial T-Z, bearing T-Z and P-Y data.

C. Modeling in SACS

Modeling the jacket structure is carried out using SACS software. The topside jacket configuration is a K-brace configuration, while the center section is an X-brace configuration. The jacket elevation will be divided to simplify the modeling and distinguish jacket member properties. The jacket structure analyzed uses steel material type S355, which is by ASTM A572. Table 4 provides specific information regarding the properties of the steel utilized.

TABLE 2.
WAVE DATA

	Wave Height (m) and Associated Periods (second) for All Direction (to which)															
Return period	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1-year																
Hs	0,34	0,32	0,26	0,50	0,40	1,94	0,65	0,39	0,40	0,33	0,40	0,60	1,55	1,29	0,53	0,37
Tp	3,07	2,97	2,98	3,48	5,31	6,54	4,70	3,25	3,31	3,25	3,23	3,53	5,84	5,20	3,28	3,17
Tz	2,39	2,31	2,32	2,71	4,13	5,09	3,66	2,53	2,57	2,53	2,51	2,75	4,54	4,04	2,55	2,47
Hmax	0,68	0,64	0,52	1	0,8	3,88	1,3	0,78	0,8	0,66	0,8	1,2	3,1	2,58	1,05	0,74
Tmax	2,76	2,67	2,68	3,13	4,78	5,89	4,23	2,93	2,98	2,93	2,91	3,18	5,26	4,68	2,95	2,85
100-years																
Hs	1,30	1,55	1,75	1,81	1,35	4,74	3,86	1,25	1,41	1,40	1,35	2,38	3,07	2,16	1,46	1,23
Tp	4,65	5,61	5,55	6,28	8,63	10,12	10,05	6,22	5,25	5,24	5,53	7,97	7,95	6,97	5,66	4,41
Tz	3,62	4,36	4,32	4,88	6,71	7,87	7,82	4,84	4,08	4,07	4,3	6,2	6,18	5,42	4,4	3,43
Hmax	2,6	3,1	3,5	3,62	2,7	9,48	7,72	2,5	2,82	2,8	2,7	4,76	6,14	4,32	2,92	2,46
Tmax	4,19	5,05	5	5,65	7,77	9,11	9,05	5,6	4,73	4,72	4,98	7,17	7,16	6,27	5,09	3,97

TABLE 3.
CURRENT DATA

Layers and Distance from Water Surface, z (m) = 61,05		Current Speed (cm/s) and Direction (to which)							
		N	NNE	NE	ENE	E	ESE	SE	SSE
1-year									
Layer 10 - Surface (1,0 D)	0	18,7	16,9	19,8	34,0	61,9	61,7	21,2	13,1
Layer 5 - Mid Depth (0,5 D)	30,53	16,9	15,3	17,9	30,8	56,1	55,9	19,2	11,9
(1m ASB)	60,05	11,7	10,6	12,4	21,3	38,8	38,7	13,3	8,2
100-year									
Layer 10 - Surface (1,0 D)	0	100,9	103,4	125,1	153,5	360,2	390,8	190,5	130,9
Layer 5 - Mid Depth (0,5 D)	30,53	63,3	64,8	78,4	96,2	225,7	245,0	119,4	82,1
(1m ASB)	60,05	91,4	93,6	113,3	139,0	326,2	354,0	172,5	118,6
		S	SSW	SW	WSW	W	WNW	NW	NNW
1-year									
Layer 10 - Surface (1,0 D)	0	10,0	10,1	10,4	17,7	45,0	61,4	34,7	23,6
Layer 5 - Mid Depth (0,5 D)	30,53	9,1	9,2	9,4	16,0	40,7	55,6	31,4	21,3
(1m ASB)	60,05	6,3	6,3	6,5	11,1	28,2	38,5	21,7	14,8
100-year									
Layer 10 - Surface (1,0 D)	0	96,5	97,8	114,7	143,3	197,9	249,0	169,9	131,1
Layer 5 - Mid Depth (0,5 D)	30,53	60,5	61,3	71,9	89,8	124,1	156,0	106,5	82,2
(1m ASB)	60,05	87,4	88,6	103,9	129,8	179,2	225,5	153,9	118,7

TABLE 4.
MATERIAL CHARACTERISTIC OF THE STRUCTURE

Material Characteristic	SI Unit	=	Imperial Unit
Ultimate Tensile Strength	450 Mpa	=	65300 psi
Yield Tensile Strength	345 Mpa	=	50000 psi
Modulus of Elasticity	200 Mpa	=	29000 ksi
Poissons Ratio	0.260	=	0.260
Shear Modulus	79.3 Gpa	=	11500 ksi
Density	17850 kg/m^3	=	490 lb/ft^3

D. Model Validation

The numerical model must match the available data of the jacket structure. Measurement of error rate using Mean Absolute Percentage Error (MAPE). The magnitude of MAPE results is the average of the large percentage of errors between actual and predicted results [12]. The MAPE equation can be seen as follows:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right| \times 100 \quad (5)$$

Ai represents the true value, Fi represents the anticipated value from the model, and n represents the number of data. The MAPE value is then used to analyze the performance of the existing validation accuracy process.

E. In-place Analysis

In in-place analysis, the evaluation is a static method that verifies the maximum unity check of the structure. The unity check (UC) for tubular members compares the stress or buckling experienced by the members and the allowable stress. If its maximum UC is less than 1, the structure is considered safe.

F. Pushover Analysis

Pushover analysis is performed using LRFD API standard code. Based on API RP-2A LRFD, if there are overstressed members at the structural design analysis stage, it is necessary to conduct an ultimate strength analysis to obtain the structure's reserve strength. The nonlinear collapse analysis method (pushover analysis) analyses ultimate strength. Pushover analysis is a method used to analyze structural collapse by applying loads gradually. It is a nonlinear analysis with incremental loading to determine the loading that causes the platform to collapse. The load that is gradually incremented is the environmental load (wave load) operating conditions. The platform will collapse after a plastic hinge form in a plastic part, leading to joint failure. In the RSR (Reserve Strength Ratio) calculation, base shear is the maximum reaction force that occurs on the ground surface due to lateral loads. The nonlinear material software (SACS) assumption of materials in pushover analysis after the material has undergone plasticity is plastic.

G. Reliability Analysis

Reliability analysis is required to determine the probability of structure failure when exposed to gradually incrementing environmental loads. The probability of failure is obtained from a Failure Mode (FM), a parameter used to determine the success or failure of the object under review. In this research, the object under review is a member that experiences 100% plasticity in the structure. More specifically, the structure is categorized as "failed" if the FM ≤ 0 or FM ≥ 1, while others are categorized as "successful" if the FM value is in the range 0 to 1. The failure mode used is equation 1, which combines axial stress (tension or compression) and bending stress. The failure mode equation is based on code API RP2 LRFD [13] as below:

$$1 - cos\left\{\frac{\pi}{2}\left|\frac{P}{P_n}\right.\right\} + \frac{\sqrt{M_y^2+M_z^2}}{M_p} \leq 1 \quad (6)$$

In determining the failure mode above, it is essential to understand the random variables involved in the failure mode equation. The variables determined in the Monte Carlo simulation are P, P_n, M_y, M_z, and M_p, with each assumed Coefficient of Variance (CoV) value [14], which can be seen in Table 7. Here is the mean and standard deviation equation for the lognormal distribution according to Rosyid [11]:

$$\mu_{\ln(X)} = \ln \mu x - \frac{1}{2}\ln(1 + V_x^2) \quad (7)$$

$$\sigma_{\ln(x)}^2 = \ln(1 + V_x^2) \quad (8)$$

$$V_x = \frac{\sigma_x}{\pi_x} \quad (9)$$

μ represents the mean value of the lognormal distribution, σ represents the standard deviation, and V represents the coefficient of variance.

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

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

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

$$Pof = \frac{number\ of\ failure}{number\ of\ simulation} \quad (10)$$

The reliability is calculated using the equation provided below:

$$K = 1 - PoF \quad (11)$$

Monte Carlo simulations are carried out using tabulations to make it easier. Simulations of 20,000 are carried out To obtain accurate results. The PoF value is recorded for each particular number so that a reliability value tends to be obtained constantly to determine the accuracy of the number of simulations.

III. Results and Discussion

A. Modelling and Model Validation

The jacket structural model does not model the topside in detail. The topside was considered a vertical load of 1050 kips applied to the tip of the jacket leg at the top. The vertical load is divided into three jacket legs, and each tip is applied to 350 kips. Not only is the vertical load used to replace the topside load, but we also consider the moment that occurs, so we also applied the wind load to the three joints at the tip of the jacket. The calculation of wind force according to the standard codes API RP2A is as follows:

$$F = (\frac{\rho}{2})(V)^2 CA \quad (12)$$

When F is the wind force, ρ.is the mass density of the air (at standard temperature and pressure), which is 0.00238 lbs^2/ft, V is the 1-hour wind speed with a return period of 100-year, which is 17.5 m/s, c is the coefficient shape, and A is the wind projection area according to the 16 directions of loading.

From the calculation of wind force with 16 directions of wind loading, the resultant force applied to the three joints at the top of the jacket, joints 0058, 0062, and 0064, respectively in the X and Y directions, is 0 kips and 0.0864 kips, 0.0599 kips and -0.0311 kips, -0.0599 kips and -0.0311 kips.

Model validation is done by looking at the total weight of the structure in SACS. The analysis can be performed if the total weight difference between the actual and the model data is less than 10%. Good validation is a critical step in ensuring that subsequent. The analysis to be performed will provide relevant and reliable results. Validation by looking at the weight of the SACS model with the report shows an error result of 2.65%, as shown in Table 5. Then, the analysis can continue.

TABLE 5.
MODEL VALIDITY

Structure Weight (kips)		MAPE Value	Exp
Actual	SACS Model		
4303	4417	2.65%	High Accuracy

TABLE 6.
UNITY CHECK OF THE STRUCTURE

Member Group ID	Critical Member	Max UC	Load Case
HB	0132-0039	0.281	OW
HB	0026-0133	0.280	OW
JL	0055-0023	0.246	OW
HB	0025-0132	0.244	OESE
JL	0050-0020	0.242	OESE

B. In-place Analysis

From the in-place analysis carried out, a stress check will be obtained so that it can be known that the member is critical of the structure. Members are declared safe if UC ≤ 1; the unity check is the ratio between actual and allowable stress. The result of the in-place analysis is that the five members with the highest UC can be seen in Table 6. The maximum UC that occurs is 0.281, far below the limit. The maximum UC occurs in critical member 0132-0039, where the member is included in the HB (Horizontal Brace) group member.

C. Pushover Analysis

Pushover analysis is used to analyze structural collapse by applying loads gradually. It is a nonlinear analysis with incremental loading to determine the loading that causes the platform to collapse. The output used is the base shear to represent the force in the pushover analysis. Base shear is the maximum reaction force on the seabed due to lateral loads. This base shear will be used as a parameter in the calculation of RSR.

This analysis is conducted to evaluate the structural integrity of the structure. The results of this analysis are given in Figure 3. The minimum RSR occurs in the direction of 135°, with load case OW. The minimum RSR value is 9.33, which is still higher as per the API, which is 0.8 minimum.

D. Reliability Analysis

The Failure Mode (FM) used refers to the LRFD API, a combination of axial load and bending moment, which can be seen in Equation 1. Members are declared fail if the FM < 0 and successful if 0 < FM < 1. The probability of failure was calculated using Monte Carlo simulations. The analysis is conducted in the direction of loading, which causes the structure to collapse the fastest (critical). Critical direction has a minimum RSR value, which is a direction of 135° with load case OW. The analysis was carried out 10,000 times for each plastic member.

After the reliability of each plastic member on the structure is known, the system's reliability is calculated using the Reliability Block Diagram (RBD). The series calculation is used on members that fail at the same increment load. While parallel calculation is used for members that fail with different increment loads

The RBD calculation scheme can be seen in Figure 4.

1) Series Calculation

For load step 40:

$$K_{LS40} = K_{0025-0132} \times K_{0026-0133}$$
$$= 0.86013 \times 0.98583$$
$$= 0.84794$$

For load step 41:

$$K_{LS41} = K_{0133-0039} \times K_{0132-0039} = 0.99989 \times 0.94672 = 0.94662$$

For load step 43:

$$K_{LS43} = K_{0106-0096} \times K_{0107-0096} \times K_{0055-0023} = 0.96904 \times 0.92297 \times 0.88741 = 0.79369$$

For load step 44:

$$K_{LS44} = K_{0050-0022} \times K_{0026-0051} \times K_{0055-0101} \times K_{0060-0055} = 0.97793 \times 0.90859 \times 0.90862 \times 0.97090 = 0.78382$$

For load step 45:

$$K_{LS45} = K_{0072-0055} = 0.92334$$

2) Parallel Calculation

$$K_{system} = 1 - [(1 - K_{LS40}) \times (1 - K_{LS41}) \times (1 - K_{LS43}) \times (1 - K_{LS44}) \times (1 - K_{LS45})$$

$$K_{system} = 1 - [(1 - K_{LS40}) \times (1 - K_{LS41}) \times (1 - K_{LS43}) \times (1 - K_{LS44}) \times (1 - K_{LS45})$$

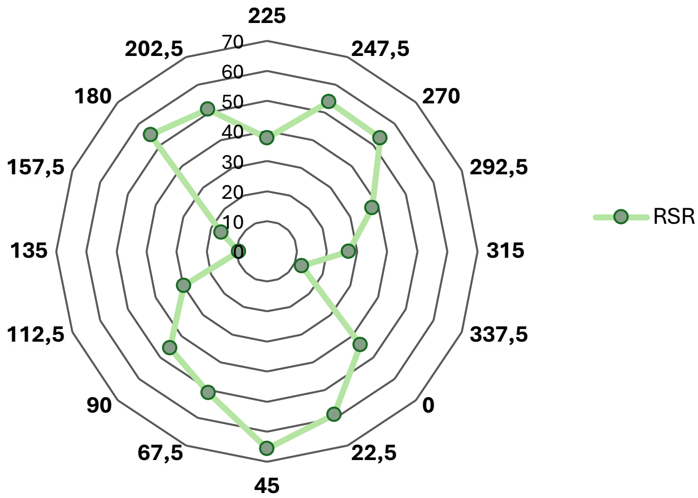

Figure. 3. RSR for various load direction.

TABLE 7.
FAILURE MODE PARAMETER

Variable	CoV	Distribution
P	0.3	Lognormal
My	0.3	Lognormal
Mz	0.3	Lognormal
Pn	0.15	Normal
Mp	0.15	Normal

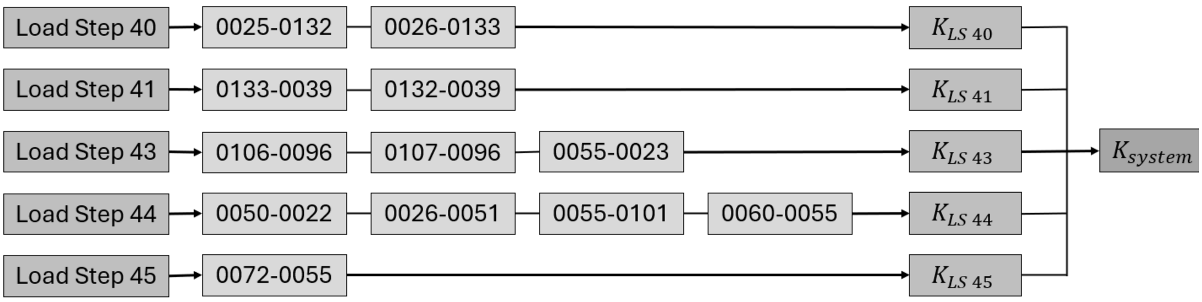

Figure. 4. Reliability Block Diagram (RBD) of the Structure

$$K_{system} = 0.99997$$

The jacket structure's reliability value, which considers the RSR value, is 0.99997. It can be said that the structure of this jacket is very reliable because, as per DNV, the minimum reliability for offshore structure is 0.999.

IV. Conclusion

From the analysis and discussion that has been carried out, several conclusions are obtained, including:

(1) The in-place analysis of extreme conditions showed that the structure is still fit to operate because the max UC of the member that occurs is 0.281, which is still far below the minimum. The member's UC<1, it can be said that the structure is safe.

(2) The nonlinear collapse analysis results show that the smallest RSR result of the structure is 9.33, with a critical direction at 135° loading direction. The RSR is still far below the minimum. As per API RP 2A LRFD, the minimum RSR is 0.8.

(3) The reliability system calculation using Monte Carlo Simulation (MCS) and Reliability Block Diagram (RBD) shows that the structure has a reliability of 0.99997. It can be said that the structure is very reliable because the minimum reliability required for offshore structures based on DNV is 0.999.

The author's suggestion in this study is that because the structure is very conventional, it is necessary to optimize the structural design for further research so that the jacket structure is not too conventional and does not make the material cost very expensive.

Acknowledgments

The authors would like to express their sincere gratitude to Ocean Engineering Post-graduate School for providing the simulation workspace and guidance during the research.

References

[1] Kementerian Energi dan Sumber Daya Mineral, “Rencana Umum Energi Nasional,” Jakarta, 2017.

[2] F. Fu, *Design and Analysis of Tall and Complex Structures*. 2018. doi: 10.1016/c2015-0-06071-3.

[3] S. Chakrabarti, *Handbook of Offshore Engineering*, vol. I. Amsterdam: Elsevier, 2005.

[4] A. A. Motlagh, N. Shabakhty, and A. Kaveh, "Design optimization of jacket offshore platform considering fatigue damage using Genetic Algorithm," *Ocean Eng.*, vol. 227, p. 108869, May 2021, doi: 10.1016/j.oceaneng.2021.108869.

[5] Y. Yu *et al.*, "Reliability-based design method for marine structures combining topology, shape, and size optimization," *Ocean Eng.*, vol. 286, p. 115490, Oct. 2023, doi: 10.1016/j.oceaneng.2023.115490.

[6] V. Murali, "Reliability-based multi-objective optimization of offshore jacket structures," in *Lecture Notes in Civil Engineering*, vol. 23, Springer, 2019, pp. 451–461. doi: 10.1007/978-981-13-3134-3_34.

[7] S. Chandrasekaran, *Dynamic Analysis and Design of Offshore Structures*. India: Springer, 2015. [Online]. Available: http://www.springer.com/series/10524

[8] API RP 2A LRFD, "Planning, Designing, and Constructing Fixed Offshore Platforms-Load and Resistance Factor Design," 2019.

[9] W. F. Krieger, H. Banon, and J. R. Lloyd, "Process for Assessment of Existing Platforms To Determine Their Fitness for Purpose," 1994.

[10] Y. Bai and W.-L. Jin, *Marine Structural Design*, Second. Elsevier, 2015. doi: 10.1016/C2013-0-13664-1.

[11] D. M. Rosyid, *Pengantar Rekayasa Keandalan*. Surabaya: Airlangga University Press, 2007.

[12] F. Petropoulos *et al.*, "Forecasting: theory and practice," *Int. J. Forecast.*, vol. 38, no. 3, pp. 705–871, 2022, doi: 10.1016/j.ijforecast.2021.11.001.

[13] American Petroleum Institute, "Recommended Practice for Planning, Designing and Construction Fixed Offshore Platform – Load and Resistance Factor Design, API Recommended Practice 2A (RP 2A) LRFD," *Off. Publ. Washington. DC*, 1997.

[14] L. E. Moses, *Think and explain with statistics*. California: Addison-Wesley Pub. Co., 1986.