REKAYASA
Journal of Science and Technology
https://journal.trunojoyo.ac.id/rekayasa

REKAYASA 19(1): 2026 pp.210-223
ISSN: 0216-9495 (Print)
ISSN: 2502-5325 (Online)

# Fatigue Sensitivity Analysis of Offshore Fixed Platform Structure in The Natuna Sea

**Nafisa Nandalianadhira [1)], Mochammad Fathurridho Hermanto [2*)], Aqsha Khaylla Riquelle[3)], Andreas Owen Hotman Nainggolan[4)]**

[1,2,3,4] Teknik Kelautan, Institut Teknologi Sumatera, Indonesia
*email: mochammad.hermanto@kl.itera.ac.id
**DOI:** https://doi.org/10.21107/rekayasa.v19i1.30551
Submitted June, 17th 2025, Accepted November, 11th 2025, Published June, 26th 2026

**Abstarct**

Offshore fixed platform is one of the various types of platforms that are very suitable to be built in water areas with not too deep depths such as the Natuna Sea Waters area. This study analyzes fatigue in an offshore fixed platform in the Natuna Sea (309 ft depth), a region suitable for such structures due to its relatively shallow waters. The platform, with its tubular joints, is susceptible to fatigue from cyclical wave loads, particularly in the braces. The research employed in-place and fatigue analyses using a deterministic method and adhering to API RP 2A-LRFD standards. In-place analysis revealed peak unity check values of 0.95 for the Pile (P1C) during operation and 0.96 for the Conductor (CO3) during storms. Maximum deflections were recorded: 14.728 inches horizontally at joint H005 and –3.339 inches vertically at joint C064. Fatigue analysis indicated a minimum service life of 73.40 years at joint 303L, located in the splash zone, where wave influence remains significant. Sensitivity analysis highlighted the crucial role of brace gap and chord thickness in determining service life. Increased brace gap negatively impacts service life, while chord thickness provides notable improvement. This research offers important insights for ensuring the structural integrity and longevity of offshore fixed platforms in similar environments and emphasizes the need for careful evaluation of stress concentration at tubular joints. Overall, the findings support more effective design considerations for shallow-water offshore structures.
**Keyword:** Natuna Sea, Offshore Fixed Platform, Fatigue, Service Life

**Abstrak**

Offshore fixed platform merupakan salah satu jenis anjungan yang sangat sesuai dibangun pada perairan dengan kedalaman tidak terlalu besar, seperti Perairan Laut Natuna. Penelitian ini menganalisis kelelahan (fatigue) pada sebuah offshore fixed platform di Laut Natuna dengan kedalaman 309 ft, yang merupakan wilayah perairan dangkal dan cocok untuk struktur jenis ini. Platform dengan sambungan tubular sangat rentan terhadap kerusakan akibat beban gelombang siklik, terutama pada bagian brace. Penelitian ini menggunakan analisis in-place dan analisis fatigue dengan metode deterministik yang mengikuti standar API RP 2A-LRFD. Hasil analisis in-place menunjukkan nilai unity check maksimum sebesar 0,95 pada Pile (P1C) saat kondisi operasi dan 0,96 pada Conductor (CO3) saat kondisi badai. Defleksi maksimum tercatat sebesar 14,728 inci secara horizontal pada joint H005 dan –3,339 inci secara vertikal pada joint C064. Analisis fatigue menunjukkan umur layanan minimum sebesar 73,40 tahun pada joint 303L yang berada di splash zone, area yang masih dipengaruhi gelombang secara signifikan. Analisis sensitivitas menegaskan bahwa jarak brace dan ketebalan chord merupakan parameter penting yang memengaruhi umur layanan. Peningkatan jarak brace menurunkan umur layanan, sedangkan ketebalan chord memberi peningkatan signifikan. Penelitian ini memberikan wawasan penting untuk memastikan integritas dan umur layanan struktur offshore serta mendukung perancangan yang lebih efektif pada anjungan perairan dangkal.
**Kata Kunci:** Laut Natuna, Offshore Fixed Platform, Fatigue, Umur Layan Struktur

© 2026 Authors

## INTRODUCTION

Petroleum and natural gas remain the main sources of energy worldwide, despite the increasing development of new renewable energy (NRE). However, the application of renewable energy is still slow and uneven, especially in developing countries like Indonesia. According to the National Energy Board's energy mix projections, the use of fossil fuels is expected to remain dominant until 2050, driven by increased energy demand due to economic and population growth (Sarante, 2024). This condition causes oil reserves onshore to deplete, so that oil and gas exploration must turn to the high seas (offshore), including Indonesian waters which have great oil and gas potential (ESDM, 2021) (Aryanto, 2023). The projected energy mix trends from 2013 to 2050 can be seen in Figure 1.

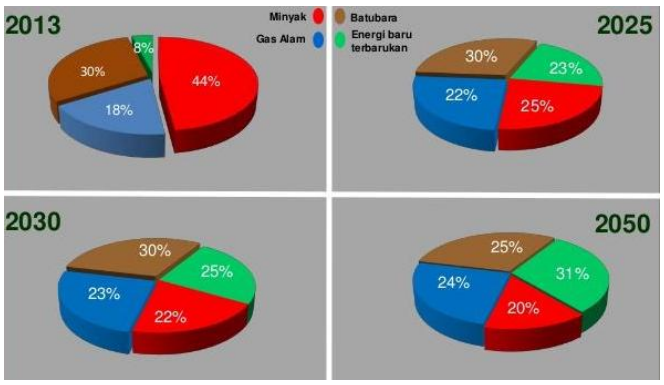



Figure 1. National Energy Mix S.D. 2050
(National Energy Council, 2013)

One of the strategic areas is the Natuna Sea, which has the largest oil and gas reserves in Indonesia and even in the Asia Pacific, with potential oil of 332.4 MMSTB and natural gas reaching 46.96 MMSTB (ESDM, 2018). Exploration in this region is very important to support national energy supply. The offshore exploration process requires supporting facilities such as offshore platform structures designed to optimize oil and gas exploitation (Purwatiningsih & Masykur, 2012)(Ignasius Danies, 2020). These structures must be able to deal with various technical challenges such as dynamic loads due to waves and ocean currents, so a reliable and efficient design is key to successful exploration in the Natuna Sea region (Rakhman, 2017)(Huang et al., 2023)(Oyegbile & Muskulus, 2024).

During its operational life, an offshore platform structure is subjected to various dynamic loads including hydrodynamic loads such as waves and currents(Clara et al., 2023)(Sykes et al., 2023)(Bashetty, 2021). Although the Natuna Sea is outside the tectonic subduction zone so seismic analysis is often neglected in design, the submerged part of the structure (jacket) constantly receives cyclical loads from waves that can cause micro-cracks (Veriyanto, Hartono Yudo, 2016)(Syalsabila et al., 2022)(Amiri et al., 2021). These cracks will progressively develop to the point of potential structural failure, making fatigue analysis crucial for optimizing designs, monitoring fatigue factors, and determining maintenance schedules - particularly at joints - through service life calculations (Paramashanti, 2023)(Simbolon, 2020). Fatigue analysis using the deterministic method is performed based on the results of the in-place analysis, referring to the API RP 2A-LRFD standard which provides load factors to consider load uncertainties while producing a reliable and dimensionally efficient structure (van de Graaf,

1994)(Zulfikar Adha et al., 2021)(Alhusein & Kadim, 2020). The output of the analysis using SACS in the form of an FTGSLT report includes a description of the load case, S-N curves, stress concentration factors (SCF) at each joint, and an estimate of the fatigue life of the structure (Mochammad Fathurridho Hermanto, 2023)(Noviyanti et al., 2021)(Ali., 2021)

In addition to the load factors from currents and waves, the characteristics of sea breeze are also important parameters that need to be analyzed in the design of offshore structures (Hermanto et al., 2024). Accurate wind data can provide a more comprehensive picture of the potential dynamic loads acting on the platform. The difference in estimation results between data sources such as ECMWF and BMKG needs to be considered because it can significantly affect the estimation of structural strength (Hermanto et al., 2025)(Kelautan, 2018)(Danarko & Rildova, n.d.). Therefore, the selection of appropriate wind data sources becomes an integral part of planning a structural design that is not only technically safe but also efficient in the long run (Penalba et al., 2022)(Ali et al., 2021).

This study aims to analyze the strength of the structure through fatigue analysis, and calculate the service life via the deterministic method. It is hypothesized that the service life exceeds the operating life. The scope includes the use of API and AISC standards, environmental data from previous studies, and JONSWAP spectrum-based analysis. In addition, this research is expected to contribute to a more detailed understanding of fatigue behavior in tubular joints of fixed offshore platforms, particularly in shallow-water environments such as the Natuna Sea. The results are intended to provide practical design insights for improving structural reliability, optimizing joint configurations, and identifying the most influential parameters affecting fatigue performance. Furthermore, the findings can serve as a reference for future engineering decisions regarding redesign, maintenance planning, and safety evaluation of similar offshore structures.

## METHOD

The structural model to be designed and analyzed is located in North Belut Field, Block B South Natuna Sea, Natuna Sea. The following is a flow chart used as a flow in this research:

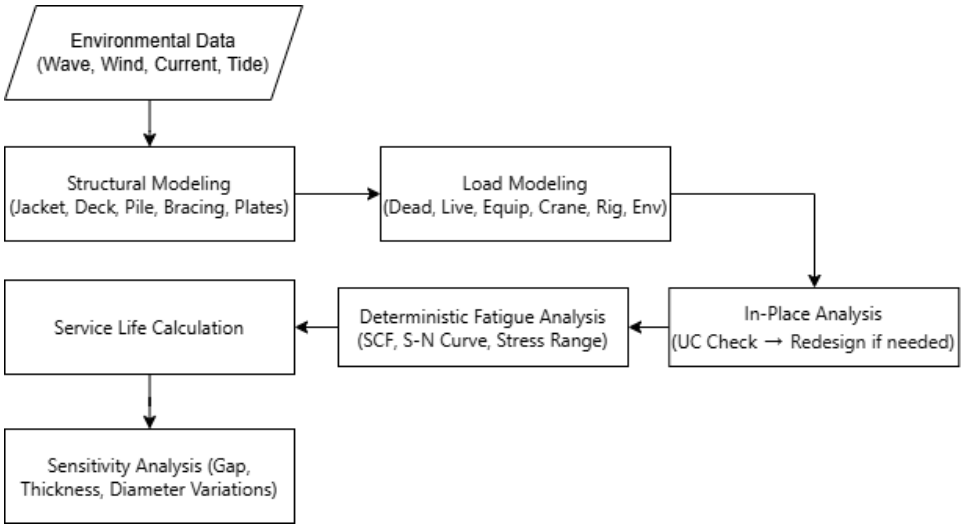



Figure 2. Flow chart of structural model

In the design there are two different wave data requirements, for in-place analysis the maximum height and period parameters are used with omnidirectional direction under operating and storm conditions. The following wave data values were used. The wave data values used are summarized in Table 1.

Table 1 Wave Data

| Return Period (year) | Maximum Wave | |
|---|---|---|
| | High (ft) | Period (s) |
| 1 | 18.4 | 8.3 |
| 100 | 33.5 | 10.1 |

The environmental data used in structural design are applied under two different conditions, namely during operation and during storms for in-place analysis. This includes water depth data, wave parameters, current speed, wind speed, and geotechnical data from the seabed. The tide data referred to can be seen in Table 2.

Table 2 Tide Data

| Parameter | Depth (ft) | |
|---|---|---|
| | Operation | Storm |
| *Mean Sea Level* (MSL) | 309 | 309 |
| *Lowest Astronomical Tide* (LAT) | -4.3 | -4.3 |
| *Highest Astronomical Tide* (HAT) | 4.3 | 4.3 |
| *Storm Surge* (SS) | 0.66 | 1.00 |
| *Air Gap* | 5 | 5 |

In addition to wave data, wind speed data is also required for in-place design under operational and storm conditions using omnidirectional direction. The wind speed parameters used are provided in Table 3.

Table 3 Wind Data

| Return Period (year) | 1-minute Wind Speed (mph) |
|---|---|
| 1 | 31 |
| 100 | 44 |

The current data used in the design is the same as wind data, which only consists of current speed parameters with omnidirectional direction, but the current data used represents two current profiles, namely on the surface and seabed. The current velocity data is summarized in Table 4.

Table 4 Current Data

| Return Period (year) | Current Parameters | |
|---|---|---|
| | Elevation | Velocity (ft/s) |
| 1 | *Surface* | 2.62 |
| | *Mudline* | 2.30 |
| 100 | *Surface* | 2.95 |
| | *Mudline* | 2.62 |

Wave data is one of the critical environmental parameters in offshore structure design. It provides insight into the frequency, direction, and magnitude of wave loads that the structure

will experience during its operational life. The distribution of wave occurrences based on direction and wave period is illustrated in Figure 3.

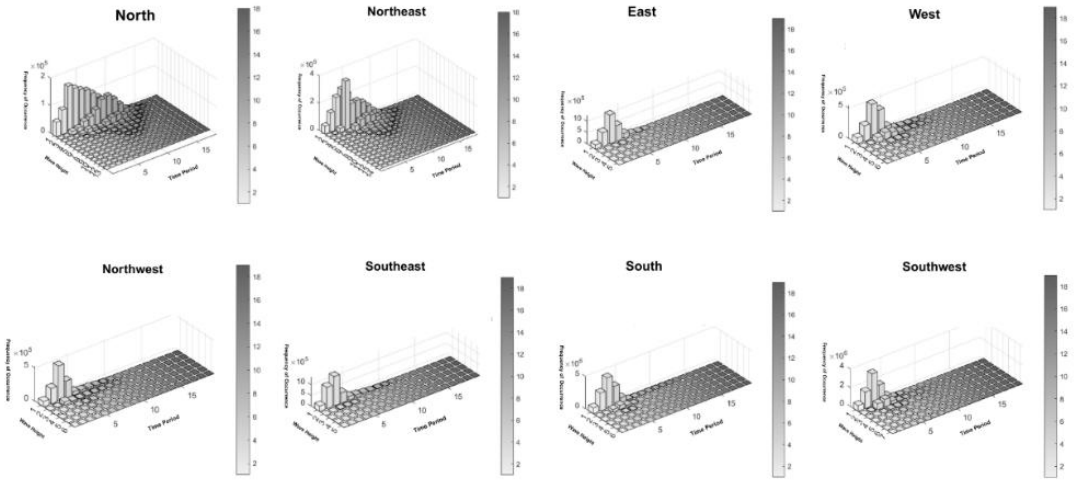



*Figure 3. Wave Occurrence*

The results of the in-place analysis provide a stress value for the member that is presented as a unity check, which is a comparison between the allowable stress and the actual stress of the member that reflects its strength.

In the initial design, the unity check value is still above 1, indicating that several structural members do not meet the required strength capacity and therefore require redesign by increasing the cross-sectional dimensions and improving the steel quality. The evaluation of member capacity in the in-place analysis refers to the axial–bending interaction equation recommended in API RP 2A-LRFD, as shown in Equation (1). This formulation combines axial compressive stress and biaxial bending stresses while considering buckling effects through Euler stresses on both principal axes. By using this interaction equation, the structural adequacy of tubular members can be assessed more accurately under combined loading. The unity check values before and after redesign, which demonstrate the improvement in member capacity after the modification, are presented in Table 5.

$$UC = \frac{f_c}{\emptyset_c f_{cn}} + \frac{1}{\emptyset_b f_{bn}} \left\{ \left[ \frac{c_{my} f_{by}}{\left(1 - \frac{f_e}{\emptyset_c F_{ey}}\right)} \right]^2 + \left[ \frac{c_{mz} f_{bz}}{\left(1 - \frac{f_e}{\emptyset_c F_{ez}}\right)} \right]^2 \right\}^{0.5} \quad (1)$$

Information:

$f_c$ = axial compressive stress (ksi)
$f_{cn}$ = nominal axial compressive (ksi)
$\emptyset_c$ = resistance factor (0.85)
$f_{bn}$ = nominal bending stress (ksi)
$\emptyset_b$ = resistance factor (0.95)
$f_{by}$ = bending stress y - axis (ksi)
$f_{bz}$ = bending stress z - axis (ksi)
$f_e$ = euler stress (ksi)
$F_{ey}$ = euler buckling y - axis (ksi)
$F_{ez}$ = euler buckling z - axis (ksi)

Table 5 Comparison of initial and final UC

| Structural Component | UC Final Design Range | |
|---|---|---|
| | **Operation** | **Storm** |
| Main Girder | 0.13 – 0.77 | 0.10 – 0.64 |
| Secondary Girder | 0.07 – 0.75 | 0.06 – 0.54 |
| Deck Leg | 0.01 – 0.90 | 0.03 – 0.61 |
| Bracing (Horizontal & Vertical) | 0.10 – 0.74 | 0.08 – 0.91 |
| Jacket Leg (L1–L5) | 0.18 – 0.40 | 0.34 – 0.82 |
| Pile (P1–P7) | 0.51 – 0.95 | 0.56 – 0.94 |
| Diagonal Bracing (V1–V4) | 0.26 – 0.43 | 0.81 – 0.93 |
| Horizontal Bracing (H1–H5) | 0.26 – 0.74 | 0.33 – 0.91 |
| Conductor Guide & Segment (CO, CSJ, CSD) | 0.36 – 0.86 | 0.32 – 0.96 |
| Risers & Riser Guide (RSR, RSJ) | 0.14 – 0.29 | 0.14 – 0.26 |
| Crane & Boat Landing | 0.52 – 0.79 | 0.02 – 0.88 |
| Flare Boom (FB1–FB3) | 0.22 – 0.52 | 0.16 – 0.40 |

The next stage focuses on deterministic fatigue analysis. Based on API, the fatigure analysis follows the Equation (2). Wave data (Hs, Ts) used from ECMWF ERA5 (1 year, 1 hour interval) and processed into water level elevation time series using JONSWAP (1968) spectra and harmonic components. If the service life of the tubular joint is less than the design life, the dimensions (diameter/thickness) are revised until they meet the safety criteria (van de Graaf, J. W., Tromans, P. S., & Efthymiou, 1994).

$$D = \sum \left(\frac{n}{N}\right) \tag{2}$$

*Information:*

$n$ = number of cycles applied at given stress range,

$N$ = number of cycles for which the given stress range allowed by the appropriate S-N curve.

The important input parameters used in the deterministic fatigue analysis are presented in Table 6. These parameters follow the theoretical basis of offshore tubular fatigue design and are consistent with API RP 2A-LRFD recommendations. The 20-year design life represents the typical operational lifespan of fixed platforms, while a safety factor of 2.0 accounts for uncertainties in environmental loads and stress-range prediction. The 10-year fatigue time period reflects representative long-term wave conditions used in the deterministic approach. The "EFT–SCF by Efthymiou" option is selected due to its wide validation for tubular joints and its ability to capture stress concentration effects from brace–chord geometry. The API S–N curve provides standardized fatigue resistance for welded offshore joints. The MMN stress calculation method captures cyclic stress ranges by evaluating maximum and minimum stresses from load combinations. A 20-degree wave step size and 18 static steps are applied to represent multi-directional wave loading efficiently without unnecessary computational demand. Together, these parameters ensure that the fatigue analysis realistically reflects environmental conditions and produces reliable estimates of structural service life.

*Table 6 Important Parameters of Deterministic Fatigue Input*

| Parameter | Information |
|---|---|
| *Safety Factor* | 2.0 |
| *Fatigue Time Period* | 10 Year |
| *SCF Option* | EFT – SCF' by Efthymio |
| *S-N Curve* | API – *American Petroleum Institute* |
| *SCF Validity Check* | Yes |
| *Stress Calculation Type* | MMN – *Stresses determined by max/min search on load cases* |
| *Wave Step Size* | 20 degrees |
| *Static Steps* | 18 |

**RESULTS**

The structure to be designed is an offshore platform structure with a fixed jacket type, this structure will be used for oil and gas drilling activities, or is included in the type of wellhead platform. There are several main configurations in the structure including having a total of 3 deck levels on the topside which can be seen in Table 4.1., this structure also consists of 4 main jacket legs that use a ratio between rise: run which is 1/8, and use an X-type bracing system.

The fatigue analysis results showing the 5 joints with the shortest service life are listed in

Table 7. Deterministic Fatigue Analysis Results

| ***Joint*** | ***Member*** | ***Member Group*** | ***Damage*** | ***Service Life (year)*** |
|---|---|---|---|---|
| 303L | 303L-403L | L3D | 0.2725 | 73.39364 |
| 403L | 303L-403L | L3D | 0.2305 | 86.75615 |
| 401L | 401L-501L | L2A | 0.2263 | 88.39777 |
| 303L | 203L-303L | L4D | 0.2170 | 92.17122 |
| 403L | 403L-503L | L2D | 0.2128 | 93.98021 |

The geotechnical data used in this design includes skin friction (T-Z), lateral bearing (P-Y) and end bearing (Q-Z) data. These data are important inputs in the fatigue analysis of the pile soil interaction file. Skin friction data provides information about the friction between the pile surface and the soil. Lateral bearing data indicates the ability of the soil to withstand lateral loads from the pile. Meanwhile, the end bearing data describes the bearing capacity of the soil at the end of the pile. These three data complement each other to ensure a safe and durable foundation design.

Structural modeling includes decks, jacket legs, and piles. Broadly speaking, the modeling in the software will model the members and plates, and define the material for each member. The isometric view of the overall structure model can be seen in Figure 4.



Figure 4. Structure Model

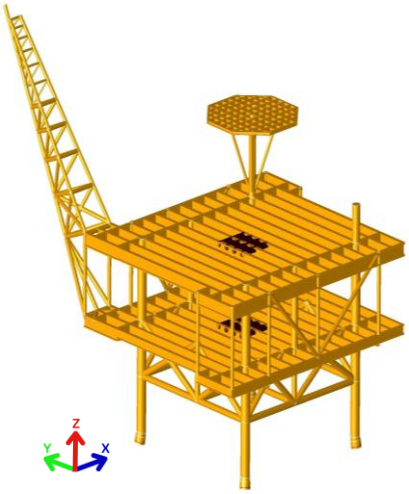



Figure 5. Overall Deck Model

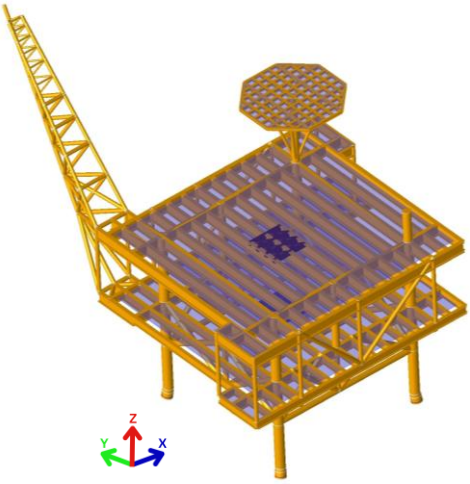



Figure 6. Plate Model on Deck

On the topside of the structure, it consists of 3 deck levels namely cellar deck, main deck, and heli deck. Determination of elevation on each deck will be at the top of steel on plate of each deck. The elevation of the cellar deck will be determined based on the value of the tidal stump parameter, maximum wave height, storm surge, air gap, and the height of the floor deck. for the elevation of the main and heli decks will be determined by the height of the floor deck and the highest equipment on the deck one level below. An illustration of the deck configuration is shown in Figure 5. In addition to modeling the cross-section of the structure, this work also modeled the plates. The plate modeling covers the entire deck floor. The plate modeling result can be seen in Figure 6. In the structural analysis software used, the variable offset on the plate must be set to top of steel which indicates that the plate is above the secondary girder and main girder.

The loading of this offshore platform structure includes several types of loads, starting with the dead load which is the weight of the structure itself, including the topside, jacket, and other components. Next, equipment loads are modeled based on equipment used for drilling, such as emergency generators, maintenance buildings, and others, which are placed on the Cellar Deck and Main Deck. Piping loads are also accounted for as live loads, which are modeled based on the location and type of piping on the Main Deck, Cellar Deck, and Flare Boom. Other live loads include operational loads on the Main and Cellar Deck, and helicopter loads on the Heli Deck. Crane loads are modeled under two conditions: operating and storm, considering vertical loads and moments. The work over rig loads located above the conductors on the Main Deck are also taken into account, both during operation and storms. Finally, environmental loads such as wind, wave, and current loads are analyzed based on eight different directions, in accordance with API RP 2A standard, with wave parameter calculations using Stokes 5 theory.

This In-Place analysis of an offshore platform structure was performed under two conditions: operating and storm. The analysis incorporates various load conditions to simulate actual field conditions, in accordance with API RP 2A-LRFD standard. The loading combinations for operating conditions include structural dead loads, equipment loads, operational live loads, piping loads, operating crane loads, helicopter loads, work over rig loads, and operational environmental loads. Meanwhile, the loading combination for storm conditions includes

structural dead load, equipment load, storm live load, piping load, storm crane load, helicopter load, work over rig load, and storm environmental load. The load factors used in these combinations refer to API RP 2A-LRFD, which are then inputted into the structural analysis software.

The analysis produces stress values in the members, which are presented in the form of unity check (UC). UC is the ratio between the allowable stress and the actual stress, which indicates the strength of the member. The initial design showed UC values above 1, indicating that the members were not able to withstand the stresses. Redesign was carried out by increasing the cross-sectional dimensions and steel grade. The final design shows a UC value below 1, which means the members have met the strength requirements. The difference in the distribution of UC values between operating and storm conditions occurs because, in operating conditions, the axial load is greater than the lateral load. While in storm conditions the opposite occurs.

The deterministic fatigue analysis was conducted to evaluate the fatigue life of the offshore platform structure, with important parameters such as a design life of 20 years, a factor of safety of 2.0, and a fatigue time period of 10 years. This analysis utilizes the EFT SCF option, API S-N curves, and MMN stress calculations.

The fatigue analysis results show five joints with the lowest service life. Joint 303L, with member 303L-403L and member group L3D, has a damage of 0.2725 and a service life of 73.39364 years. Joint 403L, also with members 303L-403L and member group L3D, has a damage of 0.2305 and a service life of 86.75615 years. Joint 401L, with members 401L-501L and member group L2A, has a breakage of 0.2263 and a service life of 88.39777 years. Another joint 303L, with members 203L-303L and member group L4D, has a deterioration of 0.2170 and a service life of 92.17122 years. Finally, joint 403L, with members 403L-503L and member group L2D, has a breakage of 0.2128 and a service life of 93.98021 years. Overall, it can be seen that despite the variation in damage, the service life of all the joints is above 70 years. The detailed results of the deterministic fatigue analysis for the joints with the lowest service life are summarized in Table 8.

Table 8. Deterministic Fatigue Analysis Results

| Joint | Member | Member Group | Damage | Service Life (years) |
|---|---|---|---|---|
| 303L | 303L-403L | L3D | 0.2725 | 73.39364 |
| 403L | 303L-403L | L3D | 0.2305 | 86.75615 |
| 401L | 401L-501L | L2A | 0.2263 | 88.39777 |
| 303L | 203L-303L | L4D | 0.2170 | 92.17122 |
| 403L | 403L-503L | L2D | 0.2128 | 93.98021 |

The results of the analysis are presented in Table 2.4 where in the table there are 3 joints with the smallest service life show in Figure 7.

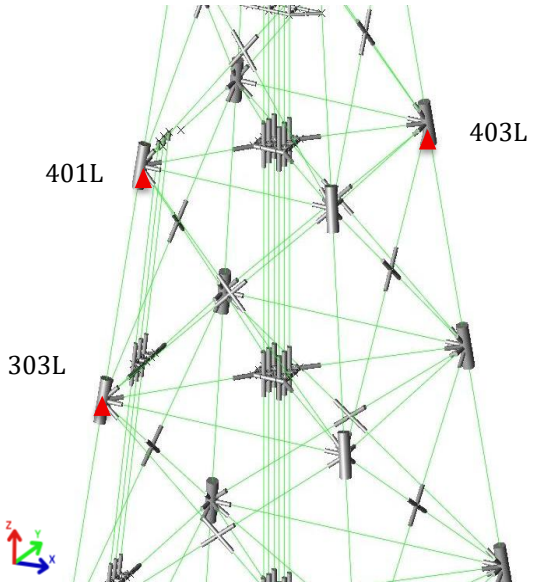



Figure 7. Structure Model

Based on the results of the deterministic fatigue analysis, the five joints with the lowest service life were identified and overall, the service life of these joints exceeds the design life of the structure, which is 40 years. Interestingly, the five joints with the lowest service life were located in the splash zone, indicating that this area is still heavily influenced by waves compared to the joints in the mid- and deepwater layers. The largest fatigue damage is dominated by the chord joints, which serve as fulcrums for various horizontal and diagonal braces, resulting in high stress concentrations at the chords. In addition, the fatigue analysis showed that the right and left sides of the braces were most susceptible to the accumulation of lateral wave loads, caused by the incident direction of the waves.

In the process of optimizing several chord members and braces with the aim of increasing the value of service life in the structure, several schemes have been carried out to see the pattern of changes in the service life value. The author conducted 6 different schemes to see the changes in service life. The joint that will be reviewed for comparison is joint 203L. The variations in service life resulting from the six optimization schemes for joint 203L are presented in Table 9.

Table 9 Changes in Service Life Value in Six Schemes

| **Scheme** | **Joint** | **Member** | **Chord Segment** | | | **Service Life (years)** |
|---|---|---|---|---|---|---|
| | | | **Diameter (in)** | **Thickness (in)** | **Gap (in)** | |
| I | 203L | 103L-203L | 48 | 0.344 | 20 | 0.03964 |
| II | 203L | 103L-203L | 48 | 0.344 | 2 | 0.48919 |
| III | 203L | 103L-203L | 48 | 0.625 | 2 | 8.15602 |
| IV | 203L | 103L-203L | 52 | 0.750 | 10 | 32.9180 |
| V | 203L | 103L-203L | 52 | 0.875 | 2 | 134.375 |
| VI | 203L | 103L-203L | 52 | 0.875 | 2 | 150.571 |

The tubular connection parameters of joint 203L, which is the focus of optimization and fatigue analysis, are visualized in Figure 8.

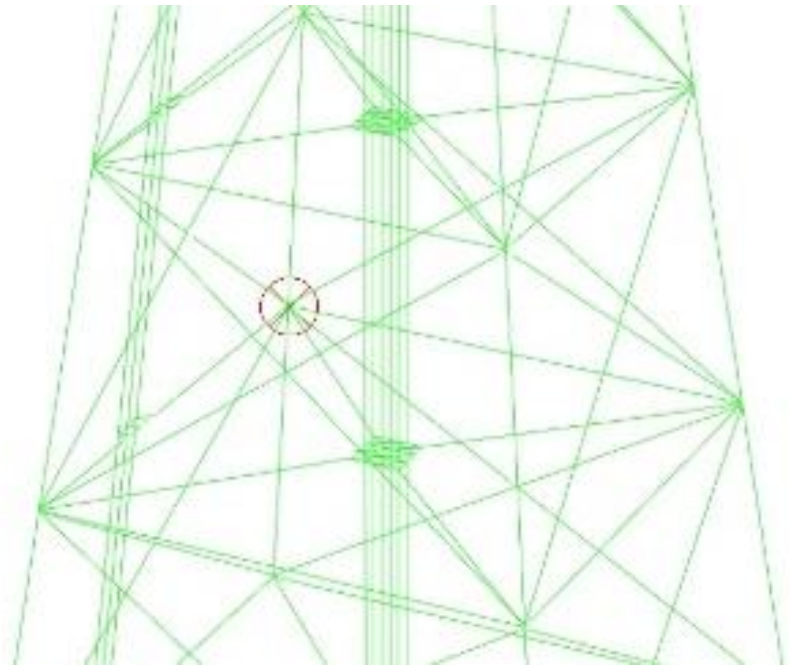


Figure 8. Visualization of Tubular Connection Parameters 203L joint

In an effort to optimize the service life of the structure, a sensitivity analysis was conducted comparing six design schemes, focusing on the 203L joint. Schemes I and II compared the effect of the gap between the braces and chord, with Scheme I using a 20-inch gap and Scheme II 2 inches. The fatigue analysis results showed that too large a gap significantly reduced the service life. Schemes III and IV explored the effect of member thickness, where Scheme III increased the thickness significantly and Scheme IV only by one level, showing that increasing the thickness increased the service life. Schemes V and VI show that increasing the chord thickness at the connection segment provides a very significant increase in service life. However, it is also worth noting that when providing segments to the chord, other segments will potentially experience an increase in stress in the member, this occurs in scheme VI where after the service life value of all joints is above the life of the structure, when the in-place analysis is carried out again, there is an increase in the value of unity check, this occurs because by dividing one tubular cross section into several parts (segments) there will be geometric discontinuities that cause stress concentration at the intersection between one segment and another segment. Therefore, it is important to perform the in-place analysis again to check the unity check value for all members.

The results of the deterministic fatigue analysis show that the critical joints of the structure primarily those located in the splash zone still exhibit a service life significantly greater than the 20-year design life, with the lowest value being 73.40 years at joint 303L. This finding aligns with the theoretical understanding that splash zone joints experience the highest stress concentration and cyclic wave loading (Clara et al., 2023)(Bashetty, 2021), making them fatigue-critical regions in offshore jacket structures. Similar observations were reported by (Noviyanti & Prastianto, 2021) who found that tubular joints located near the free-surface are more

susceptible to stress fluctuation and fatigue accumulation due to hydrodynamic amplification effects (Syalsabila et al., 2022)(Amiri et al., 2021). Their study demonstrated that joint locations near wave impact zones show higher SCF values and lower fatigue resistance, consistent with the patterns found in this research.

The sensitivity analysis performed on joint 203L indicates that geometric parameters such as brace gap and chord thickness have a substantial influence on structural fatigue performance. A large brace chord gap was shown to significantly reduce fatigue life, which agrees with Efthymiou's stress concentration model where increased eccentricity and gap spacing amplify local SCF values.(Noviyanti & Prastianto, 2021) Schemes III-VI demonstrate that increasing chord or brace thickness can improve fatigue life, which is also supported by the findings of (Syalsabila et al., 2022) who used optimization methods to show that increasing tubular thickness reduces stress range and improves fatigue resistance in offshore structures (Alhusein & Kadim, 2020; Ali, Liaqat & , Salem Bashmal, Naveed Iqbal, 2021).

Furthermore, the phenomenon observed in Scheme VI where segmentation of the chord improves fatigue life but increases unity check values reflects a classical trade-off in offshore tubular design. ( van de Graaf and P.S. Tromans, Shell Research B.V., and Michael Efthymiou, 1994) discontinuities caused by segmentation or stiffening elements may reduce fatigue damage locally but potentially introduce new stress concentration regions that must be re-evaluated through in-place analysis to ensure overall structural integrity. This theoretical behavior strongly supports the results obtained in this study, in which segmentation improved local fatigue performance but required a full UC recheck to assess its impact on global structural behavior (Penalba et al., 2022).

Overall, the findings of this study are consistent with theoretical predictions and previous research outcomes. The fatigue life results confirm that the structural redesign successfully reduced stress levels and maintained acceptable UC values(Ali et al., 2021). The sensitivity analysis provides valuable engineering insight by highlighting the decisive role of chord thickness and brace gap in determining fatigue performance, reinforcing similar conclusions in the offshore structural reliability literature (Huang et al., 2023)(Oyegbile & Muskulus, 2024).

## CONCLUSIONS

This research has successfully designed and analyzed the structure of a four-legged fixed-type offshore platform in the Natuna Sea region using a deterministic method that refers to the API RP 2A-LRFD standard. The results of the in-place analysis show that after design improvements, all structural elements have a unity check value below 1, which indicates the structure is safe against working loads and storms. From the fatigue analysis, all main connections showed a service life that far exceeded the design life of 20 years, with the lowest life of 73.39 years. The splash zone proved to be the area most susceptible to damage due to wave effects and high stress concentrations at the chord connections. In addition, sensitivity analysis revealed that the chord thickness and inter-brace gap greatly influenced the service life, where an increase in chord thickness significantly extended the life of the structure but also potentially increased stress concentrations due to geometry changes.

Based on these findings, it is recommended that the chord connection design be optimized by considering the segmentation effect so as not to cause new stress concentrations,

and revalidate through post-optimization in-place analysis. The splash zone, which is a critical fatigue area, needs special treatment such as anticorrosion coating or more intensive periodic inspections. The selection of accurate environmental data such as ECMWF data should continue to be used to support realistic load estimation. The results of this study can also be applied to similar structures in other shallow water areas. For future development, fatigue analysis can be extended using stochastic methods or a combination of deterministic and stochastic methods to obtain more representative and reliable service life estimates.

## REFERENCE

Alhusein, T. A. A., & Kadim, J. A. (2020). *Fatigue Analysis of Fixed Jacket Platform using FEM*. *11*(7), 1767–1776.

Ali, Liaqat, S. K., & , Salem Bashmal, Naveed Iqbal, W. D. 1 and Y. B. (2021). *Fatigue Crack Monitoring of T-Type Joints in Steel Offshore Oil and Gas Jacket Platform*. 1–26. https://doi.org/10.3390/s21093294

Ali, K., Li, Y., Nagamune, R., Zhou, Y., & Ur, W. (2021). *Platform motion minimization using model predictive control of a floating offshore wind turbine*. *11*, 0–4. https://doi.org/10.1016/j.taml.2021.100295

Amiri, N., Shaterabadi, M., & Kashyzadeh, K. R. (2021). *A Comprehensive Review on Design , Monitoring , and Failure in Fixed Offshore Platforms*. https://doi.org/10.3390/jmse9121349

Aryanto, Y. H. (2023). *Polaritas Transisi Energi, Transisi Berkeadilan, dn Ketahanan Nasional*. *September*.

Bashetty, S. (2021). *Review on Dynamics of Offshore Floating Wind Turbine Platforms*. https://doi.org/10.3390/en14196026

Clara, M., Martins, I., Id, M., Rouse, S., & Jf, D. (2023). Offshore energy structures in the North Sea : Past , present and future. *Marine Policy*, *152*(April), 105629. https://doi.org/10.1016/j.marpol.2023.105629

Danarko, I. K., & Rildova, P. . (n.d.). *Perancangan Struktur Anjungan Lepas Pantai Tipe Tetap Tiga Kaki Di Blok Mahakam , Kalimantan Timur*. 1–15.

ESDM. (2018). Annual Archivement of Development Report: Utilization of Natural Gas. *Kementerian Energi Dan Sumber Daya Mineral*, 120.

ESDM, K. (2021). *Hingga 2050, Gas Masih Jadi Tulang Punggung Energi Nasional*.

Hermanto, M. F., Kencana, E. R., Nandalianadhira, N., Aditia, R., & Ihsan, F. (2025). Empowering local sustainability: assessing small-scale wind energy potential offshore Enggano Island for independent renewable communities. *IOP Conference Series: Earth and Environmental Science*, *1464*(1). https://doi.org/10.1088/1755-1315/1464/1/012028

Hermanto, M. F., Nandalianadhira, N., Kencana, E. R., Khaldun, M. H. I., Hutajulu, I. D., Epipanus, D., & Samosir, J. D. (2024). Pesisir Barat Lampung Offshore Wind Characteristic in Local Renewable Energy Development Studies. *IOP Conference Series: Earth and Environmental Science*, *1298*(1). https://doi.org/10.1088/1755-1315/1298/1/012024

Huang, Y., Yu, S., An, T., Wang, G., & Zhang, D. (2023). *Investigating the Ice-Induced Fatigue Damage of Offshore Structures by Field Observations*. https://doi.org/10.3390/jmse11101844

Ignasius Danies. (2020). *Desain Dan Analisis Kehandalan Struktur Platform Braced Monopod Di Perairan Laut Makassar, Indonesia*. https://tekniklepaspantai.itb.ac.id/wp-content/uploads/sites/441/2021/12/15516057-Ignasius-Danies.pdf

J, W. van de Graaf and P.S. Tromans, Shell Research B.V., and Michael Efthymiou, S. U. E. (1994). *OTC 7382 The Reliability of Offshore Structures and Its Dependence on Design*

*Code and Environment*. 105–118. https://doi.org/10.4043/7382-MS

Mochammad Fathurridho Hermanto, N. N. (2023). *Kehandalan Struktur Anjungan Lepas Pantai Terpancang Empat Kaki di Perairan Natuna*. https://doi.org/10.21107/rekayasa.v15i3.16663

Noviyanti, I., Prastianto, R. W., & Murdjito, M. (2021). Stress Distribution Analysis of DKDT Tubular Joint in a Minimum Offshore Structure. *Rekayasa*, *14*(2), 191–199. https://doi.org/10.21107/rekayasa.v14i2.10511

Noviyanti, I., & Prastianto, R. W. (2021). *Stress Distribution Analysis of DKDT Tubular Joint in a Minimum Offshore Structure*. *14*(2), 191–199. https://doi.org/10.21107/rekayasa.v14i2.10511

Oyegbile, A. D., & Muskulus, M. (2024). Enhancing fatigue reliability prediction of offshore wind turbine jacket joints through individual uncertainties for each degree of freedom of stress concentration factor. *Marine Structures*, *96*(April), 103634. https://doi.org/10.1016/j.marstruc.2024.103634

Paramashanti, Rildova, Hermanto, M. F., & Nandalianadhira, N. (2023). Determination of Lrfd Environmental Load Factors of Offshore Platform in the North of Java Sea and Makassar Strait. *International Journal of GEOMATE*, *25*(111), 94–103. https://doi.org/10.21660/2023.111.4010

Purwatiningsih, A., & Masykur. (2012). Eksplorasi Dan Eksploitasi Pertambangan minyak Dan Gas Bumi Di Laut Natuna Bagian Utara Laut Yuridiksi Nasional Untuk Meningkatkan Kesejahteraanmasyarakat Di Kepulauan Natuna. *Jurnal Reformasi*, *2*(2), 59–67.

Penalba, M., Ignacio, J., Martinez-perurena, A., & Iglesias, G. (2022). A data-driven long-term metocean data forecasting approach for the design of marine renewable energy systems. *Renewable and Sustainable Energy Reviews*, *167*(May), 112751. https://doi.org/10.1016/j.rser.2022.112751

Rakhman, A. (2017). *Desain dan analisis kehandalan struktur wellhead platform di laut natuna*. *10*, 1–15.

Sarante, J. (2024). *Energi Baru dan Terbarukan (EBT) Sebagai Teknologi Alternatif Dimasa Depan Dalam*.

Simbolon, A. J. Y. (2020). *Desain Dan Analisis Kehandalan Drilling Production Platform Tipe Jacket Delapan Kaki Pada Perairan Laut Natuna*. 1–13.

Syalsabila, F., Prastianto, R. W., Rosyid, D. M., Teknik, J., Fakultas, K., & Kelautan, T. (2022). *Sizing Optimization Using Genetic Algorithm to Achieve Minimum Offshore Structure*. *15*(2), 129–136. https://doi.org/10.21107/rekayasa.v15i2.15102

Sykes, V., Collu, M., & Coraddu, A. (2023). A review and analysis of optimisation techniques applied to floating offshore wind platforms. *Ocean Engineering*, *285*(P1), 115247. https://doi.org/10.1016/j.oceaneng.2023.115247

van de Graaf, J. W., Tromans, P. S., & Efthymiou, M. T. (1994). *The Reliability Of Offshore Structures And Its Dependence On Design Code And Environment*. https://doi.org/10.4043/7382-MS

Veriyanto, Hartono Yudo, B. A. A. (2016). *Analisa Kekuatan Konstruksi Jacket Platform Terhadap Beban Gravitasi Dan Interferensi Lingkungan di Perairan Madura Menggunakan FEM*. *4*(June), 2016.

Zulfikar Adha, M., Fadhilah, H., Sesiyar Riyanti, F., Widya Dharma Husada Tangerang, Stik., Padjajaran No, J., & Tangerang Selatan, K. (2021). http://openjournal.wdh.ac.id/index.php/Map/index