Preliminary Finite Element Analysis on Fixed Offshore Platform Joints

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Abstract: This study investigates the structural integrity of a fixed offshore platform using finite element analysis (FEA) to compare the stresses acting on the jacket joints to withstand gravity and environmental loads at two elevation levels with the equivalent static loads (ESLs) method. The three-dimensional CAD model is precisely designed with AutoCAD software and then analysed with FEA PTC Creo software for accurate numerical analysis and stress forecasting. Material selection follows API guidelines, considering necessary properties for the analysis such as Poisson's ratio, Young's modulus, and thermal expansion coefficient. The static stress analysis indicates that the structural steel joints exhibit elastic behaviour and are well below their yield and ultimate tensile strength limits. The displacement and strain values offer details about the platform's deformation characteristics. Comparisons between elevations above and below the sea level reveal variations in stress distribution and provide valuable insights for designing and optimising fixed offshore platforms to improve their reliability.

Keywords: FEA, CAD, SACS, Jacket Joints, Marine Engineering.

1. INTRODUCTION

Offshore drilling dates back to the late 19th century when the first submerged oil wells were drilled in Ohio's Grand Lake St. Marys (Chandrasekaran, 2018). Throughout the years, there have been many offshore platforms that have been built around the world to extract natural resources from the seabed, such as oil, gas, and mineral ores, by performing various tasks, including drilling, preparing gas or water for injection into reservoirs, processing oil and gas, cleaning produced water before dumping it into the ocean, and providing accommodation. Offshore platforms are large structures that can be fixed to the ocean floor, transform into artificial islands, or float in the water (Amaechi *et al*., 2022; S. Chakrabarti *et al*., 2005; Chandrasekaran, 2018; Zhang *et al*., 2022). Offshore platforms ranging from fixed to floating platforms are operating in varying water depths: shallow (<120 m), mid (121-305 m), deep (306–1219.5 m), and ultra-deep (>2285.69 m). Fixed platforms are typically used in shallow water, while floating structures are used from mid- to ultra-deep water (Amaechi *et al*., 2022). Figure **1** shows different types of offshore platforms, include fixed platforms, compliant towers, sea stars, floating production systems, subsea systems, and spar platforms (Zhang *et al*., 2022).

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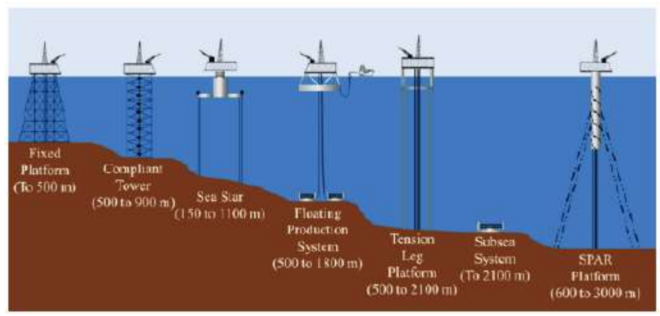

Figure 1: Different types fixed offshore platforms (Zhang *et al*., 2022).

The focus of this study is the design and analysis of the fixed offshore platform, as shown in Figure **2**, which is anchored to the seafloor by tubular steel or concrete caissons that are conventionally piled into the ocean floor as a foundation to provide stability in shallow water. The fixed offshore platform, consisting of welded tubular steel, includes a deck and surface facilities (S. K. Chakrabarti, 1987; McKenna *et al*., 2021). The deck and jacket serve as a foundation for the facilities on the surface, and pilings are driven into the ocean floor to secure the jacket. The water depth at the intended location determines the platform's height. The deck installation process involves fastening the jacket and then adding additional modules for drilling, production, and crew operations. Before installing the topside modules, barge-mounted cranes position and fasten the jacket. Economic considerations limit the development of fixed (rigid) platforms to waters no deeper than 1500 feet (or approximately 500 meters), as it is not cost-effective for deep water due to the need for lengthy legs. A jacket is an offshore platform's tubular supporting structure made of four, six, or eight 7- to 14-foot-diameter tubes that have been welded together with pipe braces to create a stool-like shape. A weight and a 7-ft diameter pile, which extends hundreds of feet below the mud line, anchor the jacket to the ocean floor. The standard base size is 400 feet by 500 feet, and skirts are added to help the jacket become fixed to the ocean floor, and the dimensions at the water's edge can reach 150 feet on each side.

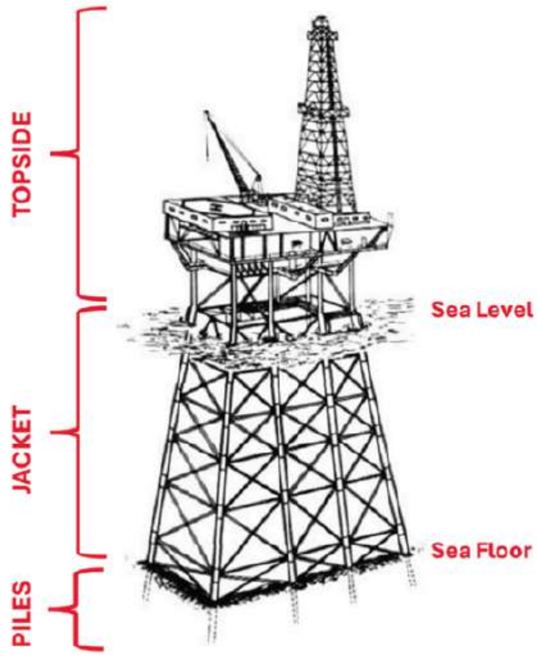

Figure 2: Fixed offshore platform structural components, modified from (S. Chakrabarti *et al*., 2005).

The industry will select the most effective design from among the many diverse types already designed for use in their sector. In this study, AutoCAD software will be used to make the first design of the fixed platform by using information from the Bentley SACS (Structural Analysis Computer System) handbook (Bentley System, 2020), and then this design will be exported to PTC CREO software for stress testing on different jacket leg joints using the Finite Element Analysis (FEA) method. AutoCAD is a computer-aided design and draughting software widely used by architects and engineers. It has replaced the traditional manual draughts process and allows for efficient design, draughts, modelling, and analysis. AutoCAD offers both two-dimensional and three-dimensional capabilities, enabling users to create detailed drawings, annotate designs, and generate isometric views (Chandra, 2021). PTC Creo is another type of 3D CAD software developed by PTC that has finite element analysis (FEA) capabilities to simulate and analyse the behaviour of 3D models under various conditions, such as stress, heat transfer, and vibration, allowing engineers to perform simulations directly within their design workflow (Chang, 2022).

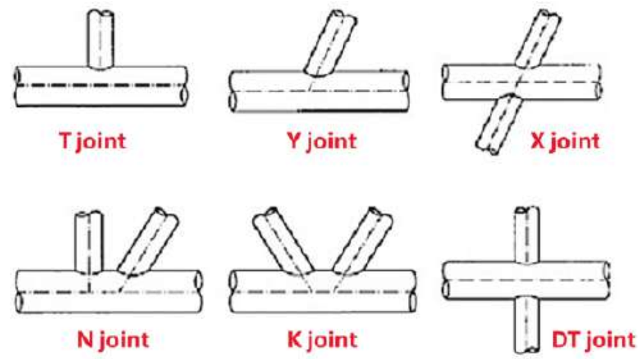

Figure 3: Type of Jacket Joints (Z Yang, 2013).

The problem addressed in this study is acquired for the design and development of a detailed and accurate jacket platform that is capable of withstanding various loads and stresses. The design and analysis of offshore platforms follow recommendations from organisations like the American Petroleum Institute (API) (American Petroleum Institute, 2014) and the PETRONAS Technical Standard (PTS) (Khan *et al*., 2020; Petroliam Nasional Berhad (PETRONAS), 2025). Factors such as transportation, current conditions, and 100-year storm events are considered during the design process. Material selection for the jacket, the main structural component of the platform, involves choosing appropriate steel grades based on factors like structural requirements, environmental conditions, and corrosion resistance. In summary, offshore platforms play a vital role in extracting natural resources from the seabed, and fixed platforms are commonly used in shallow water. The design and material selection for these platforms are guided by industry standards and considerations for structural integrity, environmental conditions, and longevity (American Petroleum Institute, 2014). In this study, the jacket design for offshore platforms includes different types of joints, such as T joints, X joints, K joints, and others, as shown in Figure **3**, which were modelled and analysed with AutoCAD and PTC Creo software, respectively. Each type of joint has its characteristics and suitability for specific structural requirements (Z Yang, 2013).

Conductor pipe installation, a preliminary step in drilling petroleum wells, frequently involves the use of specialised drills or spudder rigs before drilling operations commence. The conductor serves as a foundation and guide for subsequent drilling activities. These beam structures can be represented as line segments with a concentrated mass at the centre of gravity, and the calculations can be performed on these idealised structures as well as safety factors derived from experience, which can be done with FEA. The principle behind FEA is to divide complex continuous geometries into smaller, simpler elements with different types of elements, based on their geometric and analysis complexities, as shown in Figure **4** (Hsu, 2018; Robert Norton, 2019). FEA enables the simulation and solution of complex problems that are not feasible with common analytical and numerical methods in various engineering disciplines, such as heat transfer, fluid dynamics, acoustics, and electromagnetics, as it employs a complex numerical method to solve complex mathematical and physics problems (Bathe, 2014; Robert Norton, 2019).

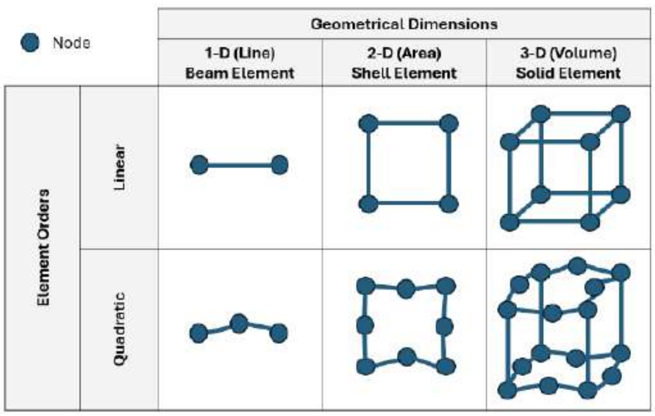

Figure 4: Types of finite elements, modified from (Robert Norton, 2019).

2. METHODOLOGY

For the development of this study, the three-dimensional CAD model of the fixed offshore platform consisting of piles, jackets, and topside was created based on the 2D drawing, then FEA meshes of solid elements were generated, and lastly, FEM analysis was conducted with consideration of relevant loads and boundary conditions.

2.1. CAD and FEA Models

A comprehensive and accurate 3D model of the fixed offshore platform was created using AutoCAD, as shown in Figure **5**. The 3D model was then imported into FEA software (PTC CREO) for further analysis and simulation using FEM. A finite element meshing was established, where the model was divided into smaller elements of connected nodes, such as triangles and quadrilaterals, as illustrated in Figure **6** for a jacket joint structure, indicating how the discretisation process has been applied to enable further analysis and simulation using FEM. The mesh density needs to be optimised to ensure a balance between accurate stress predictions and the efficient utilisation of computational resources (Bathe, 2014; Hsu, 2018; Robert Norton, 2019).

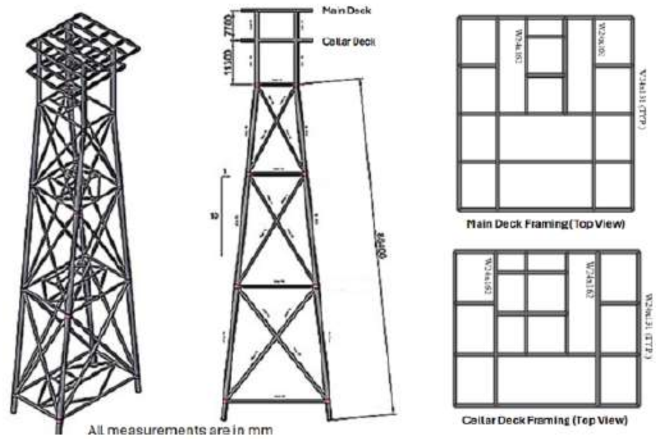

Figure 5: 3D model and 2D drawing of the fixed offshore platform.

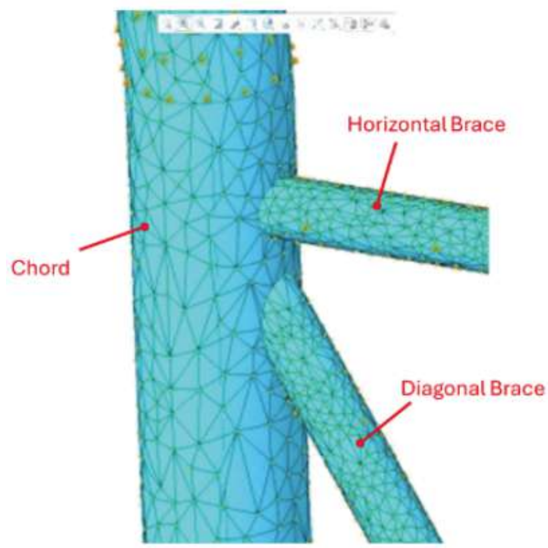

Figure 6: Finite element meshes of a jacket joint structure at EL(+)2000.

In FEA, Von Mises stress, minimum principal strain, and displacement (or deformation) are the three key parameters for evaluating structural integrity and performance under loads or pressures, where Von Mises stress predicts the material yielding, minimum principal strain indicates the material’s tendency to fracture (tensile failure), and deformation shows the physical changes of the structure under stress (Bathe, 2014; Hsu, 2018; Robert Norton, 2019). These parameters are typically visualised as a function of arc length to indicate the material's potential to yield or fracture under loads or pressures, which is helpful for understanding the stress distribution and identifying critical areas within the investigated structure (Bathe, 2014; Robert Norton, 2019).

2.2. Loads

The expected loads acting on fixed offshore platform structures can be simplified into two types (AS Kharade & SV Kapadiya, 2014): gravity and environmental loads, where gravity loads arise from the dead weight of the structure and facilities, either permanent or temporary, and environmental loads are dependent on meteorological and oceanographic conditions of the region, such as wind, wave, current, and soil (seismic and seabed movements) (Martínez *et al*., 2025), as illustrated in Figure **7**. Environmental loads are highly significant in governing the design of offshore structures (AS Kharade & SV Kapadiya, 2014), where wave, current and wind are identified as the most significant factors (Di Nicola *et al*., 2024; Martínez *et al*., 2025). Gravity load is expected to contribute 60% to 70% of the total imposed load, while the rest is from the environmental loads, where waves and currents contribute 90% of the total environmental loads and wind contributes 10% (Zulkipli Henry *et al*., 2017). The characteristics and parameters of these loads can be referred to API Recommended Practice 2A-WSD (API RP 2A-WSD) (American Petroleum Institute, 2014) and the respective oceanographic authorities or institutions.

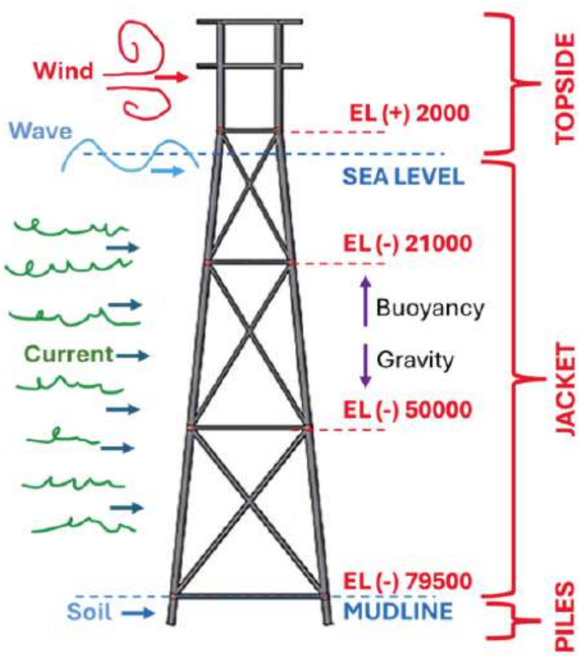

Figure 7: Environmental loads on a jacket type offshore platform.

2.3. Materials Selection

The selection of materials with appropriate properties in this study is critical to maintaining structural integrity and safety. The API RP 2A-WSD (American Petroleum Institute, 2014) document provides specific material for the planning, designing, and constructing fixed offshore platforms, which includes the recommended structural steel pipe group, class, specification, and grade. The necessary material properties were extracted from the selected material (ASTM A501) for the FEA analysis in this study, which is summarised in Table **1**.

3. RESULTS AND DISCUSSIONS

FEA analysis on the 3-D model is then conducted to simulate the behaviour of the jacket joints at two elevation levels (EL(+)2000 and EL(-)21000), as shown in Figure **7**, to ensure the design meets the necessary strength and safety requirements, as outlined in API RP 2A-WSD (American Petroleum Institute, 2014). This comprehensive analysis will evaluate the platform's structural integrity, assess its ability to withstand various loads and stresses, and ensure its overall safety and reliability.

For this preliminary study, the equivalent static loads (ESLs) method (Martínez *et al*., 2025; Park, 2011) is used to combine gravity and environmental loads for the final static analysis under extreme conditions. The main and cellar decks are simulated with evenly downward loads of 1934.87 kN and 444.82 kN, respectively, as shown in Figure **8a**. Additionally, gravitational and buoyancy loads act on the structure, as shown in Figure **8c**. Above sea level, only the gravity load acted on the structures, while both the gravity and buoyancy loads acted below sea level. Generally, the loads can be derived as weight ($F_w = mg$) and buoyancy force ($F_b = \rho Vg$), where m is the mass, ρ is the density, V is the volume, and g is the gravitational magnitude of 9.81 m/s^2. A typical jacket structure requires at least 10% to 15% reserve buoyancy, where the tubular members are carefully selected with an $F_b/F_w > 1.0$ ratio, and F_b can be calculated with either marine or rational methods (AS Kharade & SV Kapadiya, 2014).

To understand environmental loads, we need to conduct specific studies at the site, which include measuring the average water level (MWL) by looking at

Table 1: Material Properties of ASTM A501 (American Petroleum Institute, 2014)

Material Property	Value	Description
Poisson ratio, υ	0.29	The ability to withstand deformation under tensile and compressive stress
Density, ρ	7800 kg/m3	Mass/Volume
Young's modulus, E	200 GPa	The ability to resist stiffness and bending
Tensile Yield Stress, σ_Y	250 MPa (36 ksi)	The elasticity limit stress
Ultimate Tensile Strength, σ_{UTS}	400 MPa (58 ksi)	The fracture limit stress
Thermal Expansion Coefficient, α	12.1/C-1	The expansion due temperature changes

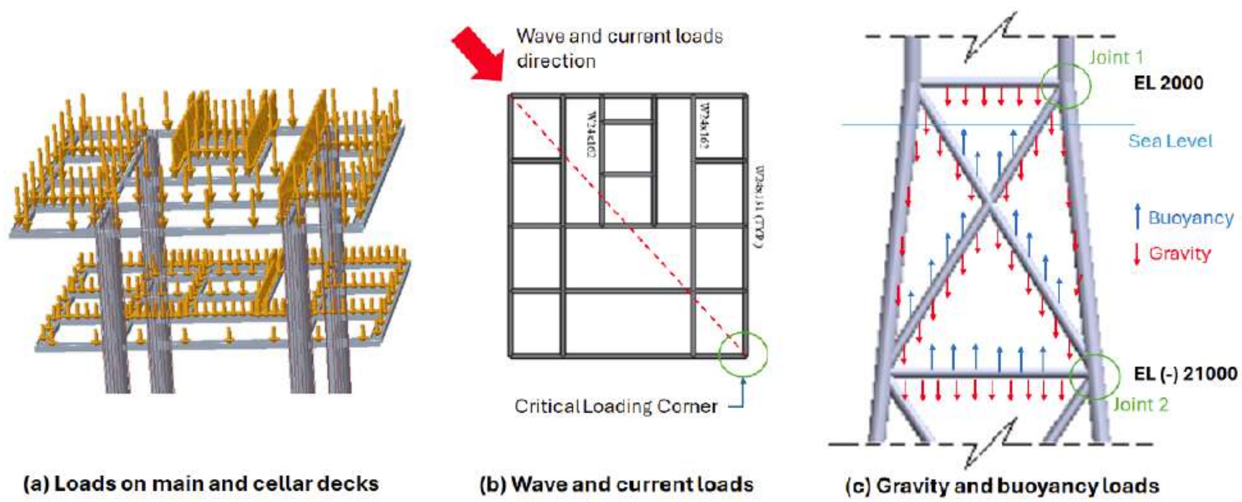

Figure 8: Loads acted on the platform structures.

Table 2: Extreme Environmental Loads (100-Year RP) Acting on the Platform Structure, Bentley SACS Handbook (Bentley System, 2020)

Load Type	Parameter	Equation (American Petroleum Institute, 2014)	Total Force
Wind	Velocity = 45.17 m/s	$F = 0.6v^2AC_s$ *v* is the wind velocity *A* is the projected of the exposed area to the wind C_s is the shape coefficient	*Not considered*
Wave	Height, h = 12.19 m	Morison's Equation: $F = C_D \frac{w}{2g} AU\lvert U\rvert + C_m \frac{w}{g} V \frac{\delta U}{\delta t}$ C_D is the drag coefficient C_m is the inertia coefficient *w* is the weight density of sea water *g* is the gravitational acceleration *A* is the projected area normal the cylinder axis per unit length *V* is the displaced volume of the cylinder per unit length *a* is the fluid acceleration	*50.03 kN*
	Period, t = 15 s		
Current	Velocity at Bottom, v = 0.514 m/s		
	Velocity at Surface, v = 1.081 m/s		

wind, waves, tides, and currents; taking soil samples; and checking conditions like seismic activity (and ice, if necessary). In this preliminary study, the environmental loads are calculated using a nominal 100-year return period (RP) for environmental factors in extreme conditions, based on the Bentley SACS handbook

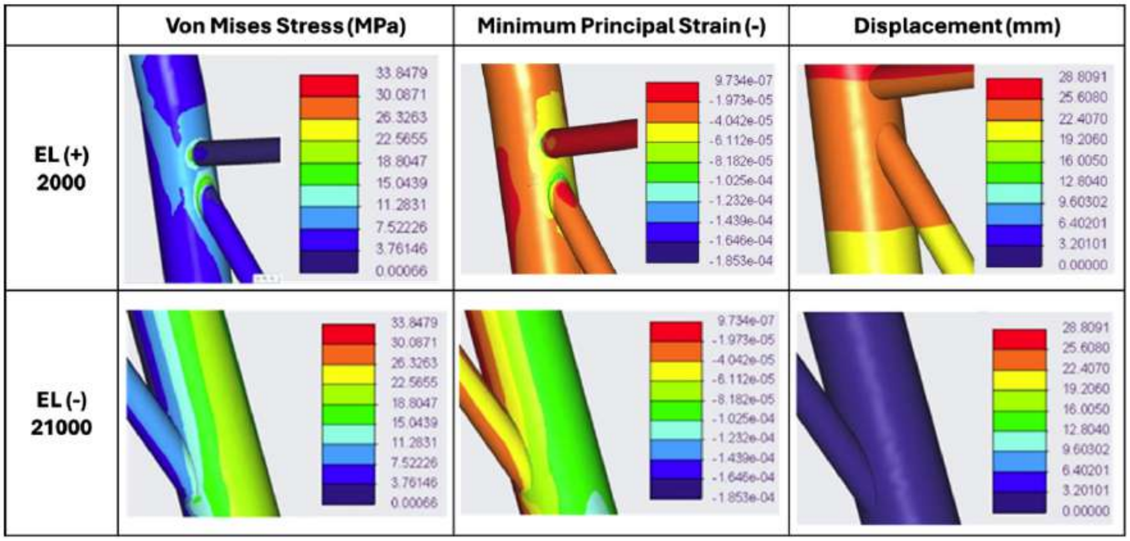

Figure 9: FEA results of stress, strain, and displacement at EL(+)2000 and EL(-)21000.

(Bentley System, 2020) for a water depth of 79.5 m (+1.5 m tide), as shown in Table **2**. The wind and current loads are assumed to be constant in the same direction and side at 10-m height, as shown in Figure **8b**. Therefore, the jacket joints that are located on the corner sides opposite to the direction of the wind, waves, and current are likely to experience the most critical axial load and shear combination (Demir, 2005), which was accounted for in this study (the two joints in Figure **8c**). This preliminary study did not consider cyclic or dynamic changes, as it is a static analysis. The wind load is not considered, as the deck equipment and structures were not modelled in this simulation, and it is expected to contribute only 3 - 4% of the total imposed load (Zulkipli Henry *et al*., 2017). Furthermore, other loads such as soil, ice, equipment, fluid, and drilling were not considered, and these loads should be completed before starting the detailed design.

Figures **9** and **10** summarise the results of stress, strain, and displacement of jacket joints at EL(+)2000 and EL(-)21000 using FEA. Figure **9** shows an overview of the FEA, while Figure **10** presents a detailed analysis using the arc length function to accurately track the stress changes along the edges of the jacket joints, which are the most important parts to be inspected for the jacket structures. This finding indicated that the jacket joints are subjected to varying levels of stress along their arc length, ranging from 9.8730 to 23.9180 MPa and 2.0762 to 11.6178 MPa for EL(+)2000 and EL(-)21000, respectively, which are significantly below the yield stress (250 MPa) of the selected material and therefore likely exhibit elastic behaviour. The minimum principal strain in the jacket material at both joints is observed to be close to zero, and as expected, the displacement magnitude increases nonlinearly as the tensile load increases. The result is due to the material becoming more compliant as it is stretched, which means that it will require less force to stretch further. For both joints, the results revealed that displacement magnitude consistently increases as the curve arc length progresses from the initial point until it reaches the maximum at approximately the midpoint and then gradually decreases, indicating a continuous deformation and movement along the curve.

Table **3** summarises these findings in detail. The stress, strain, and displacement at EL(+)2000 are generally higher than those at EL(-)21000. This conclusion is confirmed with previous studies where the above sea level platform (topside) structures experience heavy loads from the wind and waves that contribute significant loads to the platform structure (Di Nicola *et al*., 2024; Martínez *et al*., 2025; Zulkipli Henry *et al*., 2017), where the wave load is amplified as the water depth increases but the current velocity decreases exponentially with depth (Demir, 2005; Martínez *et al*., 2025). Therefore, these loads are expected to generate substantial horizontal force and produce high bending stresses on topside structures and high bending moments on the piles at the base (Demir, 2005). Additionally, structures below sea level (jacket structures) experience buoyancy that reduces their effective weight, while structures above sea level experience full self-weight plus topside loads (AS Kharade & SV Kapadiya, 2014; Demir, 2005). Based on the drawing and data above, the EL(+)2000 joint is in a wave-dominated region.

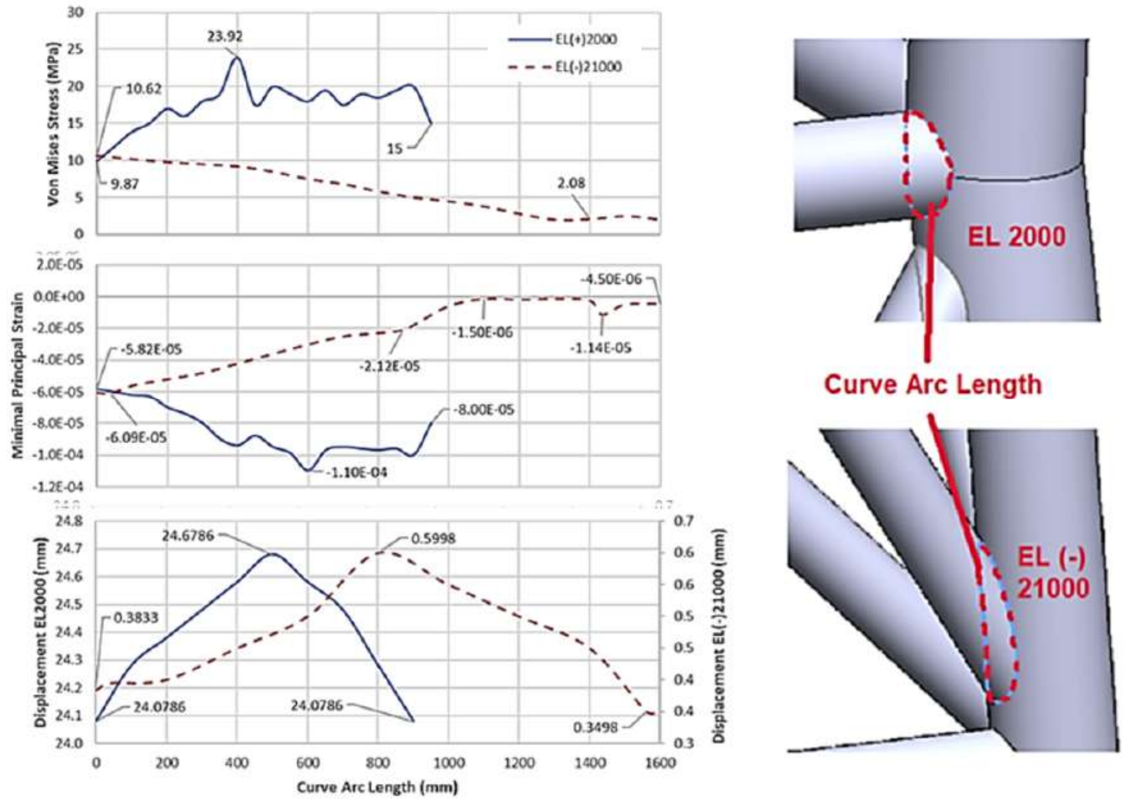

Figure 10: Stress, strain and displacement vs curve arc length.

Table 2: Summary of FEA Stress, Strain, and Displacement at Two Joints

Elevation Level (EL)	Stress (MPa)	Strain (-)	Displacement (mm)
+2000	9.873 to 23.918	-5.82E-05 to -1.018E-04	24.079 to 24.679
-21000	2.076 to 11.618	-6.039E-05 to -1.138E-06	0.350 to 0.600

4. CONCLUSION AND RECOMMENDATION

A static analysis of a jacket joint of an offshore fixed platform has been studied using PTC Creo FEA software. The platform was modelled using AutoCAD based on the API RP 2A-WSD guidelines. Stress, strain, and displacement of two joints at different elevation levels (+2000 and -21000) under gravity and environmental loads (waves and current) were investigated. This study predicts overall behaviour accurately, and the following conclusions can be drawn:

- Structures located on the sides opposite to the direction of environmental loads, such as wind, waves, and current, are likely to experience the most critical combination of axial load and shear.
- The stress on both joints is well below the tensile yield (250 MPa) and ultimate tensile (400 MPa) stresses, indicating that the structure is safe and reliable.
- Waves and currents significantly affect the structural integrity of the platform, which is expected to account for 30% to 40% of the imposed loads.
- Structures above sea level (topside) are exposed to waves (the wave load increases with depth) and higher current loads (the current load decreases with depth), and therefore, their stress, strain, and displacement are much higher than those of structures below sea level. Furthermore, structures below the surface of the water experience buoyancy that reduces their weight.

However, the analysis in this study is still incomplete, and a more comprehensive evaluation that takes into account additional design criteria and relevant factors has to be considered to ensure that the overall safety and reliability of the offshore fixed platform are not jeopardised before starting the detailed design. Following are a few recommendations:

- To complete the platform model by incorporating all essential decks, modules, and equipment, including living quarters, heliport, crane, process, utilities, and drill rig modules.
- To consider other loads, such as wind, soil, ice, equipment, fluids, and drilling.
- To include more joints, nodes and members of the structure in the analysis, particularly in the wave zone area, where the wave loading is highest.
- To perform dynamic operations, which involve construction, transportation, installation, and drilling operations.
- To conduct fatigue analysis to ensure the overall long-term performance and structural integrity of the design.
- To consider marine growth, particularly at the splash zone, that accumulates with time and has a significant effect on increasing the loads (due to roughness and diameter change) on offshore structures.
- To include other influencing factors, such as corrosion and structural surface textures.
- To validate the FEA with experimental study, manual calculations, or other numerical methods.
- To continue using advanced numerical analysis tools and consulting with experienced engineers to further optimise the design.

This study indicates that FEA is a powerful tool and played a crucial role in ensuring that the designed structure could withstand the anticipated loads before its actual construction. This preliminary study is maybe inadequate; however, it sheds some light on the understanding of the offshore fixed platform design concept and FEA, and the recommendation above may provide some improvement in the future work.

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