

# Design Simulation of Ultimate Loading Leg Jacket with Different Types of Bracing

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**Abstract:** The structural performance of fixed offshore jacket platforms is strongly governed by the configuration of their bracing systems, which control global stiffness, load transfer mechanisms, and member utilization. This study presents a comparative linear static analysis of four common jacket bracing configurations—X-bracing, V-bracing, K-bracing, and diagonal bracing—under operational and extreme storm loading conditions. Numerical simulations were performed using the Structural Analysis Computer System (SACS), incorporating realistic geometric parameters, boundary conditions, gravity loads, and environmental actions in accordance with offshore design practice. Key performance indicators evaluated include the total number of structural members, axial stress distribution along elevation, and unity check (UC) ratios for structural safety assessment. The results indicate that X-bracing provides superior load redistribution and consistently lower UC ratios across critical elevations, reflecting higher structural efficiency and redundancy. In contrast, V- and diagonal bracing systems exhibit higher member utilization, particularly at lower elevations, due to less effective load paths. The findings demonstrate that appropriate bracing selection can enhance structural efficiency while reducing material demand, supporting sustainable design strategies for offshore jacket platforms.

**Keywords:** Offshore jacket platform; Bracing configuration; Structural optimization; Unity check ratio; Sustainable offshore structures.

## INTRODUCTION

Fixed offshore jacket platforms remain a widely adopted structural solution for shallow- to medium-water oil and gas developments due to their robustness, constructability, and long-term operational reliability. The jacket structure transfers gravity and environmental loads from the topside facilities to the seabed through a system of legs, piles, and bracing members. Among these components, the bracing configuration plays a critical role in governing global stiffness, load redistribution, redundancy, and overall structural efficiency.

In offshore environments, jacket structures are subjected to combined gravity loads, wind, wave, and current actions. Inefficient bracing layouts may lead to excessive axial forces, high member utilization, and increased material demand, which negatively affect structural safety and sustainability. Although several bracing systems—such as X-bracing, V-bracing, K-bracing, and diagonal bracing—are commonly employed in practice, their relative structural performance is often selected based on experience rather than quantitative comparison under consistent modeling assumptions. Production process on platform

include wellhead, production manifold, production separator, glycol process to dry gas, gas compressors, water injection pumps, oil/gas export metering and main oil line pumps (Ronalds, 2005).

Most existing studies focus on global strength or ultimate collapse behavior of offshore jackets, while limited attention has been given to comparative assessment of bracing efficiency using utilization-based indicators under identical geometric and loading conditions (Motlagh *et al.*, 2021; Motlagh *et al.*, 2021). Moreover, the relationship between bracing configuration, material efficiency, and sustainable offshore structural design remains insufficiently explored. Since most of the oil and gas exploration and production activities occur offshore, it is crucial to provide reliable marine transport services to support these operations and fulfill their needs (Morshidi, 2009).

This study aims to address this gap by performing a systematic comparative analysis of four jacket bracing configurations using linear static analysis. The objective is to evaluate their structural behavior, member utilization, and axial stress distribution, and to identify the most efficient bracing configuration in terms of safety and material optimization.

## 1. LITERATURE REVIEWS

Offshore jacket platforms have been extensively studied due to their widespread application and critical safety requirements (Ronalds, 2005; Sadeghi, 2007).

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Previous research has highlighted the importance of bracing systems in enhancing lateral stiffness, controlling deformation, and redistributing environmental loads. X-bracing systems are often reported to provide higher redundancy and improved load paths due to the presence of alternate tensile members, whereas K- and V-bracing configurations are associated with reduced redundancy and higher susceptibility to localized member overloading. Different types of offshore oil rigs and platforms depend on the offshore oil/gas field water- depth and situation showed at Figure 1.

Several studies have investigated in-place strength and ultimate capacity of existing jacket platforms, emphasizing nonlinear pushover analysis and collapse mechanisms (Motlagh *et al.*, 2021; Motlagh *et al.*, 2021). While these studies provide valuable insight into failure behavior, they often do not offer direct, quantitative comparison of different bracing systems under the same structural and loading conditions. Recent optimization-based research has demonstrated that appropriate bracing selection can significantly reduce steel tonnage while maintaining acceptable safety margins, highlighting the potential contribution of bracing optimization to sustainable offshore design (Zheng *et al.*, 2023; Alizadeh *et al.*, 2024).

Despite these advances, many published works remain descriptive in nature or focus on specific case studies, limiting their general applicability. Furthermore, the integration of sustainability considerations—such as material efficiency and optimized member utilization—into bracing performance evaluation remains limited. This study contributes to the literature by providing a controlled comparative analysis of common bracing configurations using utilization-based

performance indicators relevant to sustainable offshore structural systems.

## 2. INTRODUCTION TO FIXED PLATFORM

A fixed platform is an offshore structure used for oil and gas production. These platforms are constructed on concrete and/or steel legs that are firmly anchored to the seabed. They have a deck that accommodates drilling rigs, production facilities, and living quarters. Fixed platforms are designed for long-term use due to their immobility.

Different types of structures, such as steel jackets, concrete caissons, floating steel, and floating concrete, are utilized. Steel jackets are vertical sections made of tubular steel and are typically piled into the seabed. Concrete caisson structures, developed under the non-deep concept, often include built-in oil storage tanks, and can be built near the shore before being floated to their final position and submerged onto the seabed. (China National Petroleum Cooperation A Transfer Platform for Supporting Offshore Oil and Gas Processing).

### 2.1. Topside Platform

The topside of a fixed platform usually houses the process facilities, living quarters, and drilling well bays. These topsides are typically constructed using I-beams and rigid steel plates. The design of topsides follows guidelines provided by the American Institute of Steel Construction (AISC), which utilizes methods like allowable stress design and load and resistance factor design. The AISC provides reliable design practices and regularly updates its guidelines based on new research. The structural steel design classes can be

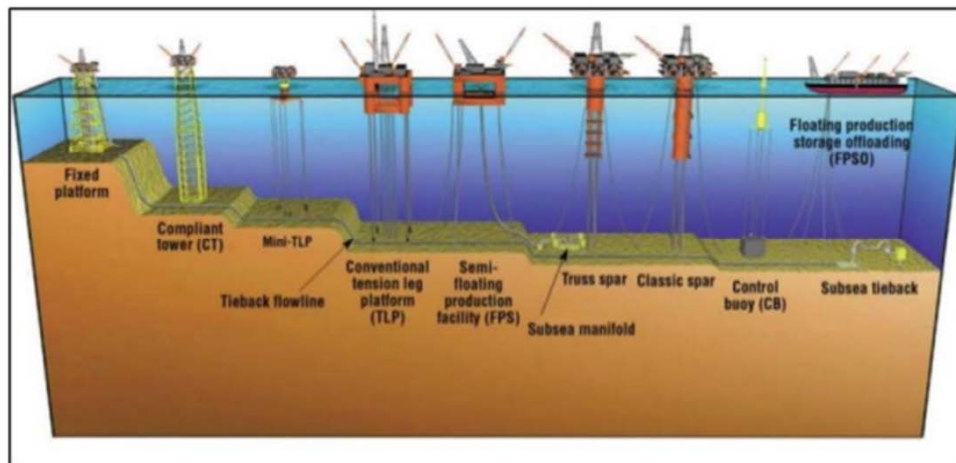
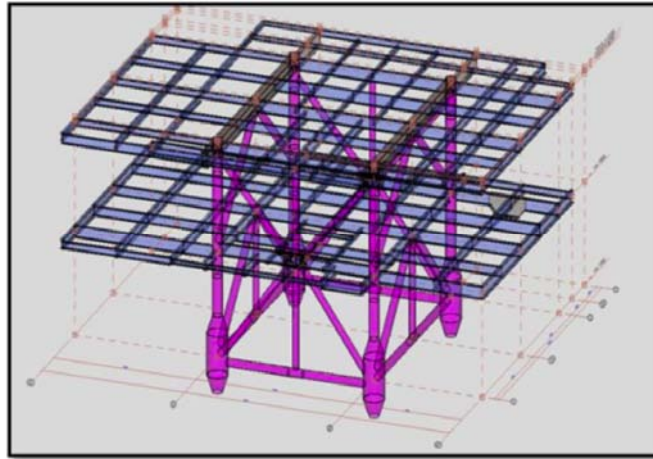


Figure 1: Type of Offshore Platform (National Ocean Industries Association, 2019).



**Figure 2:** The Topside (AVEVA, 2016).

referred to American Institute Of Steel Construction (American Institute of Steel Construction, 2011). Figure 2 provides an illustration of the topside structure.

The deck of a platform provides support for the drilling and production equipment, as well as the life support system. Different types of offshore platform decks have been developed based on operational needs and the availability of fabrication infrastructure and installation equipment. The size and layout of the deck are determined by operational requirements, including the number of deck levels and their configuration. During installation, the deck is floated over the support structure and then lowered either by ballasting the vessel or using a quick drop mechanism. In the case of a floating support structure, the support structure may be de-ballasted to accommodate the deck (Khalifeh and Saasen, 2020). The main deck, located at the top, provides support for the drilling and production systems, as well as various modules such as drilling, process utilities, living quarters, compression, and more. The cellar deck is the lower deck located beneath the rotary table on an offshore drilling rig. It provides support for systems that require placement at a lower elevation, such as pumps, utilities, pig launchers/receivers, wellhead manifolds, and piping.

## 2.2. Jacket Platform

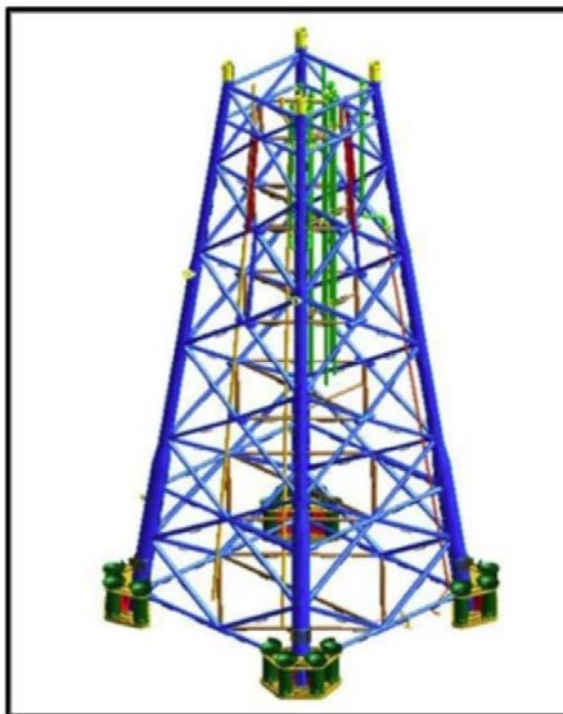
The jacket is a tower-like structure that has two main functions. It supports the production facilities above the water and also provides support and protection for the well conductors and pipeline risers. The way the jacket and piles are installed greatly affects the design. Along with supporting the deck, the jacket also supports other structures like boat landings,

walkways, and mud-mats. The jacket is made up of vertical, horizontal, and diagonal legs/braces. Joints are where these legs and braces meet. There are additional elements like bracing stubs and cans to make the joints stronger and more flexible. If the jacket needs to be transported and launched into the sea, launch runners and trusses are used. The jacket also has various accessories such as boat landings, risers, clamps, and walkways. Figure 3 shows an example of a jacket structure (Arnold and Stewart, 2008).

## 2.3. Types of Bracing

The diagonal bracing pattern has fewer braces connected to joints and lacks symmetry and redundancy. This means that all diagonal braces will either be under compression or tension, depending on the direction of the horizontal load. Because there is no backup in the form of tensile braces, if one heavily loaded diagonal brace buckles under compression, it can quickly cause the collapse of other braces and the platform. Due to these risks, this bracing pattern is rarely used and not recommended (Faseela and Jayalekshmi, 2015).

The K-brace pattern reduces welding and assembly costs because it has fewer members intersecting at joints. However, it lacks symmetry and redundancy. When all Kbraces in a level are either under full compression or tension, they do not provide tensile backup and ductility. If a brace fails due to compression overload, it can cause the structure to unzip. The K-brace pattern is used in areas where robustness is not crucial and there are no seismic loads (Faseela and Jayalekshmi, 2015). V-brace patterns have fewer braces connecting at joints, which means they lack redundancy and symmetry. They also interrupt the flow



**Figure 3:** The Jacket (AVEVA, 2016).

of load between bracing levels, resulting in larger horizontal brace sizes (Faseela and Jayalekshmi, 2015). X-bracing is a common design used in oil rig platforms. It involves diagonal members arranged in an X shape to provide stability and strength. This design improves resistance to lateral forces like wind and waves, increases stiffness, and enhances safety during seismic events. However, it requires more welding and can impact platform size. Overall, X-bracing is popular for its stability and reliability in challenging offshore environments (Faseela and Jayalekshmi, 2015).

#### 2.4. Load on Offshore Platform

Offshore structures experience two main types of loads: gravity loads and environmental loads. Gravity loads come from the weight of the structure and its components, both permanent and temporary. Seismic loads are derived from gravity loads and are specifically related to earthquakes. On the other hand, environmental loads are crucial factors in designing offshore structures. It is essential to accurately predict these loads before starting the design process. Some examples of environmental loads that affect offshore platforms are also mentioned (Kharade and Kapadiya, 2014).

The dead load consists of all the permanent items on the offshore platform, such as the platform deck, jacket, bridge, and flare structures. This includes the

main steel structural components as well as secondary items like boat landings, padeyes, stiffeners, handrails, deck plating, and small access platforms. When using computer programs to analyse the structure, the weight of the primary steel members is automatically calculated based on the structural information in the model. However, the weight of the secondary structural items needs to be manually applied to the structural model at the appropriate locations.

The offshore structure, whether for drilling or processing purposes, accommodates various equipment and facilities. These items, although fixed in place, do not contribute to the overall structural integrity or stiffness of the platform. Therefore, they should not be included in the structural model. Instead, their weights should be calculated and placed at the designated locations based on the structure's plan. Examples of such items including mechanical equipment, electrical equipment, piping connecting each equipment, electrical cable trays and instrumentation items. While environmental load such as wind loads affect the part of the platform above the water and any equipment or structures on the deck. The time interval for averaging wind speeds is an important factor to consider in wind data analysis. Wave loading is the primary environmental force that offshore structures need to consider in their design. These forces result from the movement of water

caused by waves, which are generated by the wind's impact on the sea surface.

Ocean currents exert drag forces on offshore structures, contributing to dynamic loads along with wave action. There are different types of ocean currents: tidal currents, wind-driven currents, and currents resulting from ocean circulation. Wind-driven currents are generally small and change linearly with depth, while tidal currents and currents from ocean circulation vary nonlinearly with depth. The currents generated by ocean circulation can reach speeds of up to 5 m/sec. Marine growth, such as algae, can cause added stress on offshore structures. It increases the roughness of the structure, leading to higher wave and current loads. API RP2A provides detailed information on how member roughness affects hydrodynamic coefficients. The thickness of marine vegetation generally decreases as we go deeper from the sea surface. In the splash zone, it can be as thick as 20cm, but in deeper areas, it may only be around 5cm or even negligible.

## 2.5. Design Stage on Offshore Platform

Designing an offshore structure is a multi-step process that involves several design cycles. The structural configuration, arrangement, member sizes, and specifications are refined through these cycles. The goal is to achieve an optimal design that meets the installation method and operational requirements. A project-specific design procedure should be developed to guide the design stages (Motlagh *et al.*, 2021). Here are the different stages in an offshore project's design consist of Front End Engineering Design (FEED) or concept selection, basic design and detailed design. The first step in starting an offshore project is the concept selection or FEED (Front-End Engineering Design) stage. During this stage, various disciplines including Process, Mechanical, Electrical, Instrumentation, and Structural Engineering are involved in determining the project's feasibility and selecting the best concept.

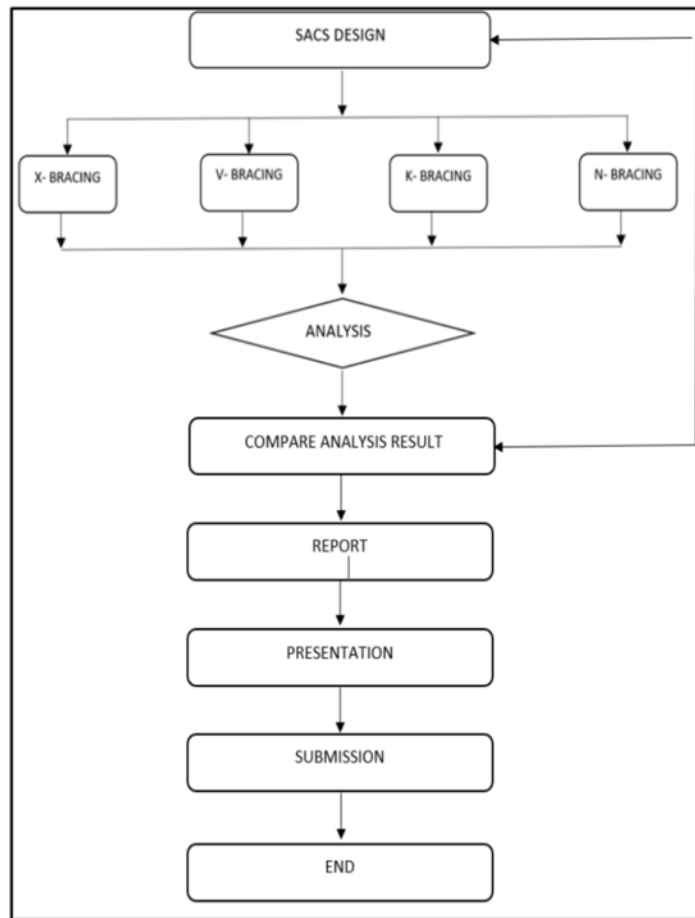
Process Data and identifying process needs and equipment including preliminary equipment sizing and area requirements, weight estimation based on passed projects, identification of structural configuration and preliminary estimation of structural weight. To furnish this simulation SACS software has been used in this study. Short time and ensure compliance in offshore structure design by utilizing the most comprehensive and current international design codes. Enhance

design accuracy and predict structural performance using a unified analysis system that allows for efficient exploration of different design options. Simplify workflows with automated structural processes, enabling the application of specialized analyses required for offshore projects (Bentley, n.d.). including nonlinear structural analysis, dynamic response analysis due to environmental loads, Impact effects analysis and several accidental loadings analyses. Offshore platforms, like topsides or jackets, are built using tubular members that are connected to create a strong framework in both horizontal and vertical directions. Tubular joints are commonly used in offshore structures, especially for jackets. These joints are created by fusion welding along the surface of the connected tubular sections. To design a tubular joint properly, two important calculations must be carried out (Sadeghi, 2007). In a three-dimensional space frame, there are various types of connections that can be found at joints where members from different directions come together. These connections can be classified into simple types based on their geometric configuration.

The UC Ratio (Utilization Check Ratio) in SACS software is a crucial parameter for assessing the utilization and stress levels of structural members. It is calculated by dividing the actual stress by the allowable stress. The UC Ratio is used to determine if a member is operating within safe limits or if there are concerns about its structural integrity. In SACS software, the UC Ratio is represented by color-coded indicators, with lower values indicating safe operation and higher values suggesting potential issues. Overall, the UC Ratio aids in evaluating member utilization and making informed design decisions for structural integrity.

Axial stress, in the context of structure modeling, refers to the internal stress experienced by structural members along their axial direction. It is calculated by dividing the axial force acting on a member by its cross-sectional area. Axial stress is essential for analyzing and designing structural components and ensuring their safety. By accurately estimating the axial stress, engineers can make informed decisions regarding material selection, member sizing, and reinforcement requirements. This helps in designing structures that can efficiently carry loads and maintain structural stability (American Institute of Steel Construction, 2011). The allowable tensile stress,  $F_t$ , for cylindrical members subjected to axial tensile loads should be determined from expressed as Equation (1)

$$F_t = 0.6F_y \quad (1)$$



**Figure 4:** The Process Flow Chart.

### 3. METHODOLOGY

#### 3.1. Introduction

To construct a platform, it is essential to have relevant data about the platform type and water depth. Building a platform requires a systematic step-by-step approach to achieve the desired outcome. The construction process begins with the fabrication of the jacket, followed by the creation of the topside surface facilities. Once the platform is completed, specific data such as load data is incorporated to ensure the platform's optimal performance. Building a platform involves gathering necessary information, constructing the jacket and topside, and integrating relevant data to achieve a well-functioning platform.

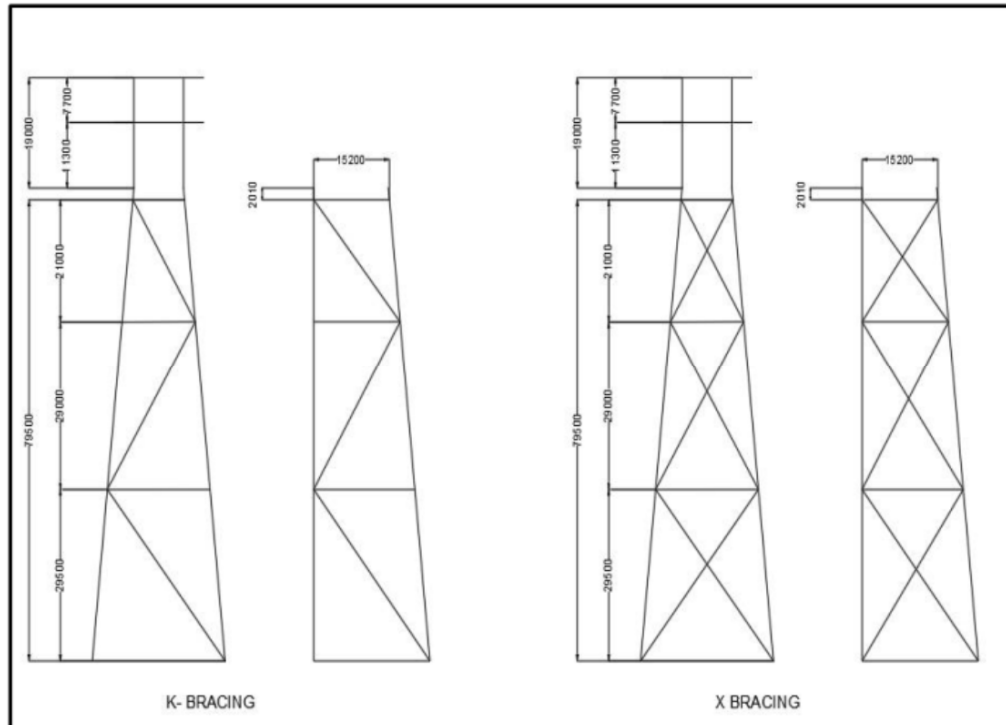
#### 3.2. The Flow Chart Method

A project flow chart is a visual representation that outlines the sequence of activities involved in completing a project shows in Figure 4. It provides a clear overview of the project's workflow, from initiation to completion, facilitating effective project

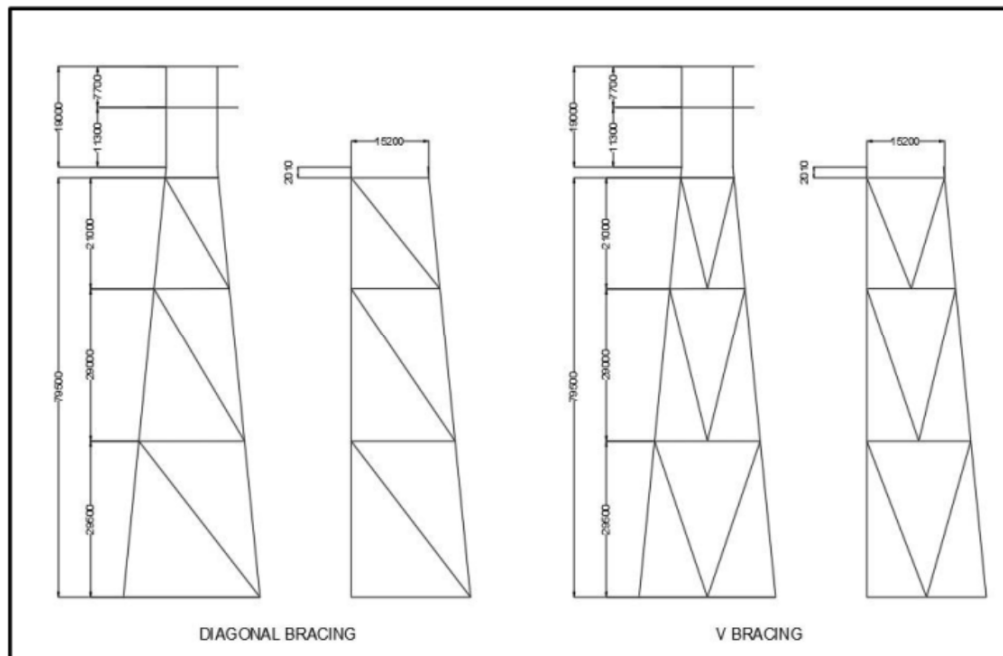
management. By following the flow chart, teams can understand the project's scope, objectives, and required steps. It promotes collaboration, transparency, and accountability among team members. Ultimately, a project flow chart streamlines efforts, enhances efficiency, and helps achieve project objectives within the defined timelines.

#### 3.3. Structural Model Description

A four-leg fixed offshore jacket platform was considered in this study. The jacket was designed for a water depth of approximately 79.5 m and supports a topside consisting of a main deck and a cellar deck. The jacket structure comprises tubular steel members connected through welded joints, forming vertical legs, horizontal frames, and diagonal bracing members. Four bracing configurations were modeled separately: X-bracing, V-bracing, K-bracing, and diagonal bracing. All models share identical geometric dimensions, material properties, and loading conditions to ensure a fair comparison shows in Figure 5 and Figure 6 for details. Structural steel was assumed to behave in a linear elastic manner. Material properties were defined in



**Figure 5:** Design for K- Bracing and X Bracing.



**Figure 6:** Design for Diagonal Bracing and V-Bracing.

accordance with offshore structural design standards, particularly the API RP 2A recommendations for fixed offshore platforms (API, 2023). Geometric nonlinearity and soil–structure interaction effects were neglected in this study to focus on comparative linear static behavior.

### 3.4. Analysis Procedure and SACS Settings

All analyses were conducted using the Structural Analysis Computer System (SACS), a widely used offshore structural analysis software package (Bentley Systems, 2020). It is a powerful tool specifically developed for structural analysis and design in the

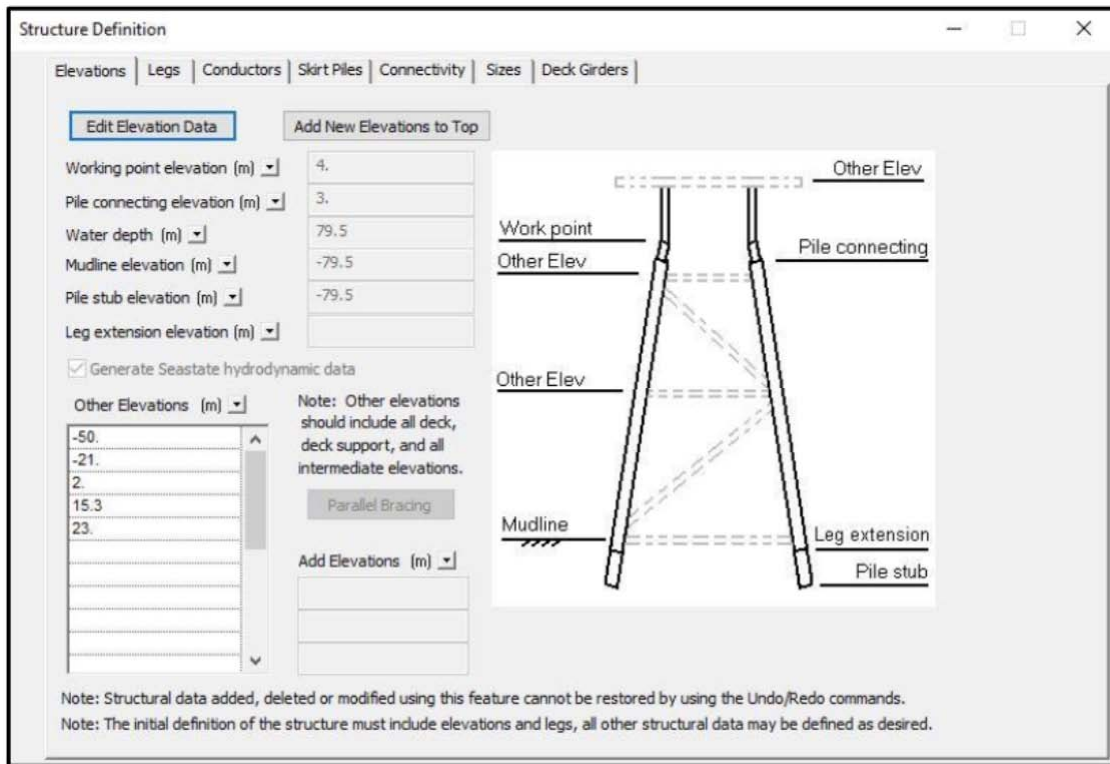


Figure 7: Structure Definition for Elevation.

offshore and marine industries. The process begins with defining the structure's geometry and components, followed by applying design parameters and loading conditions. SACS enables engineers to conduct detailed analyses, assess structural integrity, and evaluate performance under various environmental loads. It also supports design optimization, allowing for exploration of alternatives and refinement of designs. Linear static analysis was performed for each bracing configuration. Output parameters extracted from the analysis include axial forces, axial stresses, and unity check (UC) ratios for all structural members. Setting for model elevation used in this model such as water depth: 79.5 m, working point elevation: 4.0 m, pile connecting elevation: 3.0 m, mudline elevation: -79.5 m, pile stub elevation: -79.5 m, leg extension elevation: -79.5 m, other intermediate elevation: -50.0, -21.0, 2.0, 15.3 (cellar deck) and 23.0 (main deck). The overview display for this model showed in Figure 7 for details.

While model for leg jacket as number of legs: 4, leg type: Ungrouted, leg spacing at working point:  $X1 = 15$  m,  $Y1 = 10$  m shows in Figure 8 for details. The definition for the conductor as number of conductors well: 1, the top conductor elevation: 15.3 m, number of conductors in X direction: 2, number of conductors in Y direction: 2, First conductor member: 5, the location of first conductor:  $X = -4.5$  m,  $Y = -1.0$  m, the distance

between conductors: 2.0 m and disconnected elevations: -79.5 m, 3.0 m, 4.0 m showed in Figure 9 for details.

### 3.5. Bracing and Elevation design consideration

During the design consideration stage for bracing and elevation, several factors are evaluated. These include following building codes, analysing the structure's strength, distributing loads effectively, selecting the right bracing systems, addressing elevation needs, designing suitable foundations, choosing materials wisely, and incorporating sustainability principles. It's important to analyse the forces at play and distribute loads correctly. The choice of bracing systems and elevations depends on the structure's specific characteristics. Table 1 shows the types of bracing: Diagonal, X, K, And VLive load and dead load are defined on this stage with the output model showed in Figure 10 for details. While Table 2 showed setup for extreme storm towards model with the Figure 11 for details.

The structural models were subjected to gravity loads, including dead loads and live loads associated with the topside facilities. Environmental loads consisted of operational and extreme storm conditions, including wind, wave, and current actions. Load combinations were defined in accordance with offshore

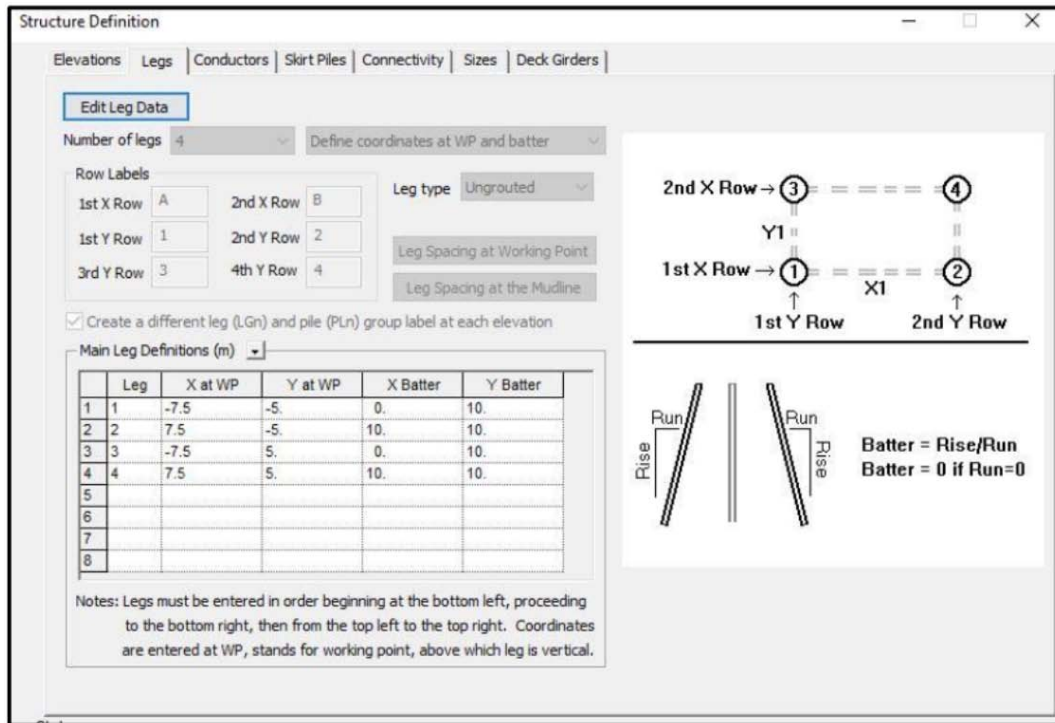


Figure 8: Structure Definition for Legs.

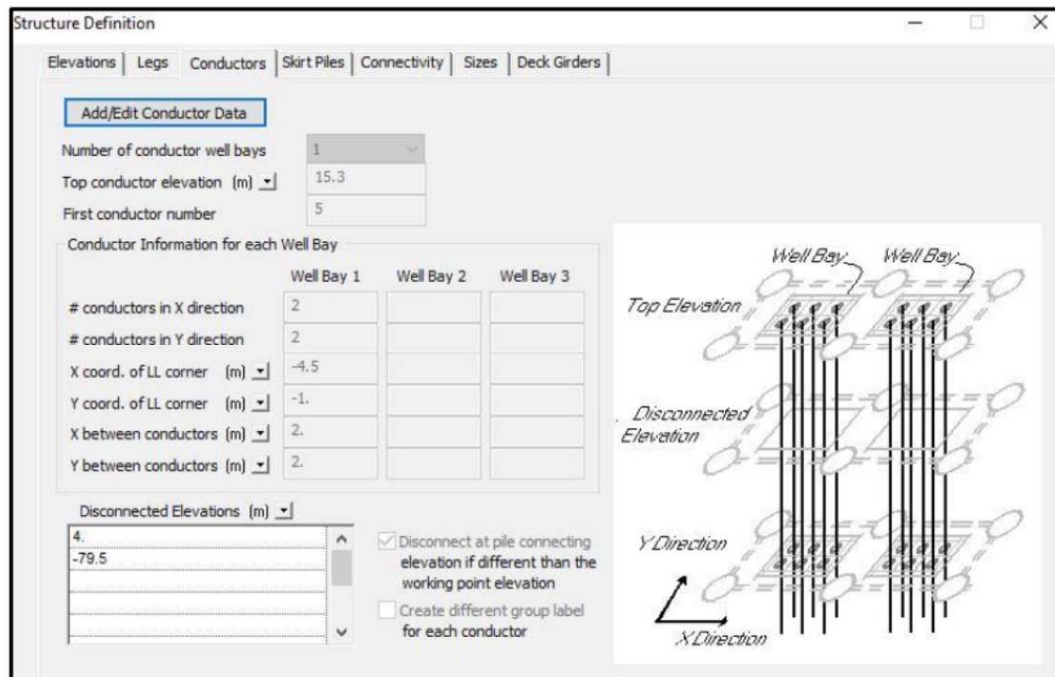


Figure 9: Structure Definition for Conductor.

design practice to represent realistic operating scenarios.

### 3.6. Boundry Conditions

The jacket legs were assumed to be connected to piles embedded in the seabed. For the purpose of

linear static analysis, the pile–soil interaction was idealized using fixed boundary conditions at the mudline. This assumption represents a comparative modeling simplification adopted to ensure consistent evaluation of all bracing configurations and does not represent detailed pile–soil interaction behavior in final design.

Table 1: Operating Storm Data

ENVIRONMENTAL LOAD OPERATING STORM			
<b>MARINE GROWTH</b>			
Bottom	Top	Thickness	Density
0	60	2.5 cm	1.4
60	79.5	5.0 cm	1.4
<b>OPERATING STORM</b>			
<b>PARAMETERS</b>			
Wave I			
Wave type	Stream		
Wave height (m)	6.1		
Period (sec)	12		
Wave direction	0		
Kinematic factor	1		
<b>OPERATING STORM WIND</b>			
<b>PARAMETERS</b>			
Wind I			
Velocity (m/sec)	25.72		
Wind height variation	AP08		
Wind direction (deg)	0		
Member load	None		
<b>OPERATING STORM CURRENT 1</b>			
<b>PARAMETERS</b>			
Current I			
Distance (m)	Velocity (m/sec)	Direction (deg)	
0	0.514	0	
79.5	1.029	0	
<b>OPERATING STORM DEAD</b>			
<b>PARAMETERS</b>			
Dead			
Buoyancy method	he - distributed load		
Direction of gravity	-Z		
Flood condition override	None		
Water depth override (m)	-		
include the buoyance below the mudlin	√		
<b>OPERATING SYSEM CURRENT 2</b>			
<b>PARAMETERS</b>			
Current II			
Blocking factor option	Auto		
Blocking factor ref. elevation (m)	-5		
Current stretching option	Linear		

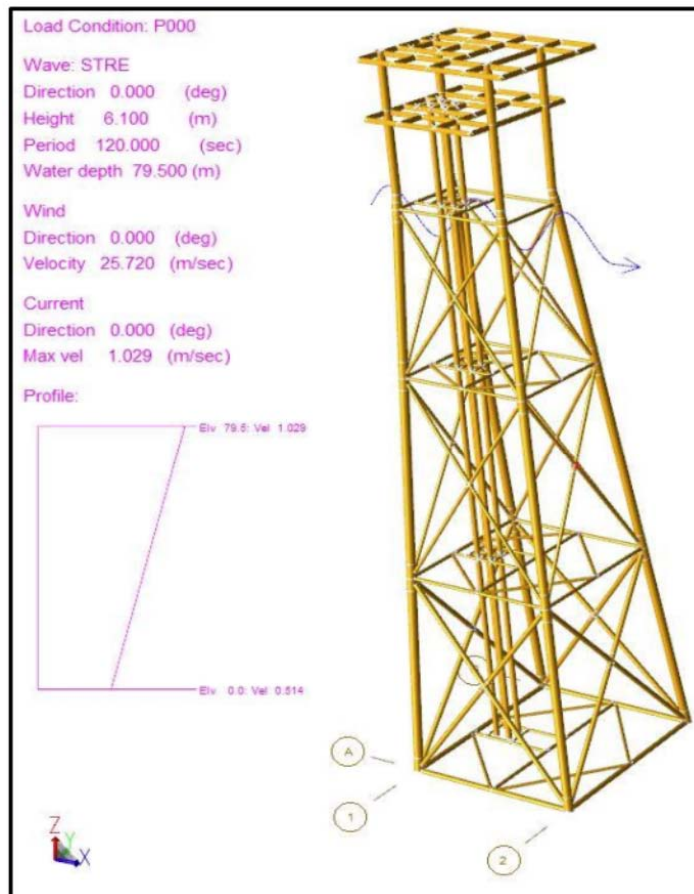


Figure 10: Operating Storm Towards Model.

Table 2: Extream Storm Data

ENVIRONMENTAL LOADS EXTREME		
PARAMETERS		
Wave I		
Wave type	Stream	
Wave height (m)	12.19	
Period (sec)	15	
Wave direction	0	
Kinematic factor	1	
PARAMETERS		
Wind I		
Velocity (m/sec)	45.17	
Wind height variation	AP08	
Wind direction (deg)	0	
Member load	None	
PARAMETERS		
Current I		
Distance (m)	Velocity (m/sec)	Direction (deg)
0	0.514	0
81	1.801	0
PARAMETERS		
Wave II		
Definition units	Degrees	
Initial crest position origin(deg)	0	
Wave position stepsize (deg)	20	
Number of crest position	18	
Critical position	Max base shear	
Still water depth override (m)	81	
Maximum member segmentation	10	
Minimum member segmentation	1	
Print option	Minimum print	
PARAMETERS		
Current II		
Blocking factor option	Auto	
Blocking factor ref. elevation (m)	-5	
Current stretching option	Linear	
PARAMETERS		
Dead		
Buoyancy method	Line- Distributed load c	
Direction of gravity	-Z	
Flood condition override	None	
Water depth override (m)	81	
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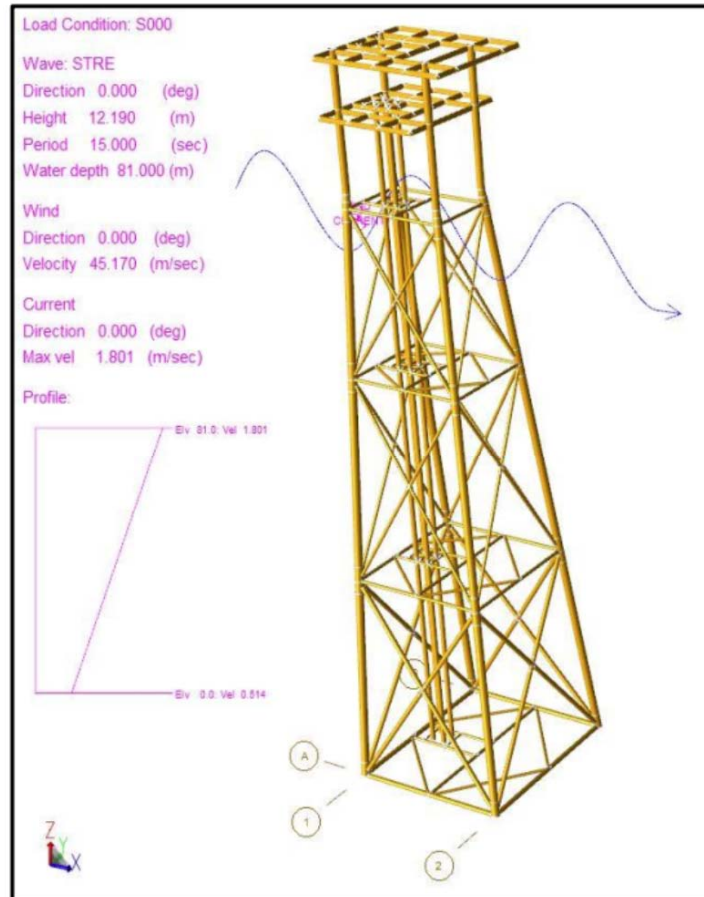


Figure 11: Extreme Storm Towards Model.

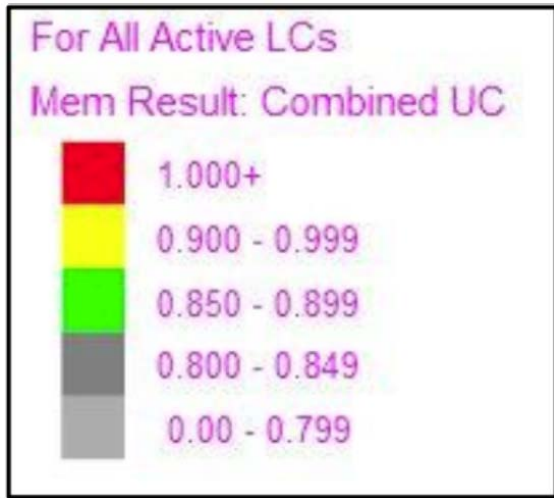


Figure 12: The Colour Indicator UC Ranges.

## 4. RESULTS AND DISCUSSION

### 4.1. Unity Check (UC) indicators

The result and discussion section of a project analysis using SACs (Structural Analysis and Design) software is essential for presenting and interpreting the outcomes of the analysis. SACs software is widely used in structural engineering to analyse various structures. This section provides detailed information on structural behaviour, load distribution, and stability. The UC Ranges color indicator in SAC software represents the utilization or stress levels of structural

components in a visually intuitive manner. The color gradient, ranging from green to red, indicates the utilization ratios of elements. Lighter shades of green indicate low utilization, while darker shades of red indicate high utilization.

The UC Ranges indicator in SACS software signifies the utilization ratios of structural components. A value below 1 indicates that the component operates within a safe range and can handle the applied loads. Keeping UC ranges below 1 ensures structural integrity and safety.

### 4.2. Result for Model Bracing and Unity Check (UC) Ratio

To The UC Ratio ranges provide valuable insights into the utilization and stress levels of the bracing members. Lower values within the range of 0.0-0.49 indicate that the members are operating safely, while higher values within the range of 0.5-0.99 and 1.0-3.0 suggest increasing utilization and potential concerns. Upon analysis in Figure 13a, it is evident that Xbracing demonstrates a notable number of members (340) within the lower utilization range (0.0-0.49), indicating effective load distribution and resistance. This signifies a well-utilized bracing system.

However, it is worth noting that all types of bracing exhibit members within the higher utilization ranges

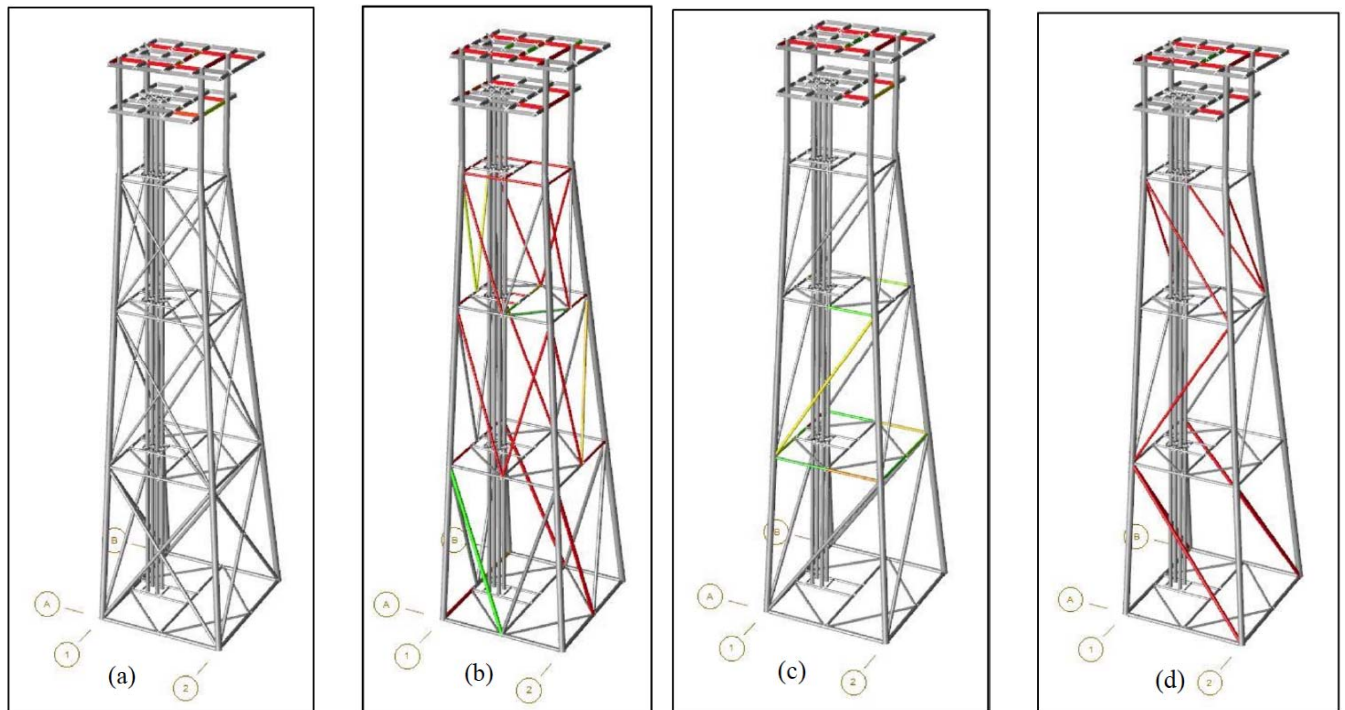


Figure 13: Results for Model a) X-Bracing, b) V-Bracing, c) Diagonal Bracing d) K-Bracing.

**Table 3: Unity Check (UC) Ratio Results**

		UNITY CHECK (UC) RATIO		
		0.0-0.49	0.5-0.99	1.0-3.0
TYPES OF BRACING	X- Bracing	340	21	10
	K- Bracing	290	26	20
	Diagonal- Bracing	278	45	12
	v- Bracing	220	82	47

(0.5-0.99 and 1.0-3.0), suggesting the presence of elements operating at elevated stress levels. Close attention is necessary to prevent these members from nearing their capacity limits and compromising the overall structural stability. Evaluation of their design, including specific locations, load distributions, and potential modifications, becomes crucial for optimizing their performance.

Meanwhile, K-Bracing shows in Figure 13c) indicated higher UC Ratio 290(0.0-0.49) and 20 (1.0-3.0) if compare with Diagonal-Bracing in Figure 13d) respectively.

When comparing the different types of bracing, variations in utilization patterns become apparent. V-bracing demonstrates in Figure 13b) shows a significant number of members within the higher utilization ranges (0.5-0.99 and 1.0-3.0) compared to other bracing types. This implies areas within the V-bracing system where members experience heightened stress levels, necessitating further investigation and potential design enhancements to ensure adequate strength and stability. In summary, the results of the UC Ratio analysis underscore the importance of assessing the utilization levels of bracing members in the structure. Identification of members operating within higher utilization ranges allows for focused implementation of design adjustments and reinforcement strategies, ensuring structural integrity and safety. Additionally, these findings inform decisions related to optimizing bracing systems and selecting appropriate members, facilitating the creation of an efficient and well-utilized structure.

### 4.3. Axial Load Stress Results

The obtained results provide insights into the relationship between axial stress and the Unity Ratio (UC Ratio) for different bracing types at various

elevations. The UC Ratio serves as an indicator of the utilization or stress levels of structural components, calculated by dividing the actual stress by the allowable stress. After studying the data, is evident that the axial stress values exhibit variations across elevations and bracing types, while the allowable stress remains constant for each bracing type are shown in Table 4. Considering the diagonal bracing, at elevation -21, the actual stress of 71.25 N/m<sup>2</sup> falls below the allowable stress of 198.35 N/m<sup>2</sup>, resulting in a UC Ratio below unity. Similarly, at elevations -50 and -79.5, the actual stress values (88.45 N/m<sup>2</sup> and 57.45 N/m<sup>2</sup>, respectively) remain within the permissible limits, yielding UC Ratios below unity. Analysing the X-bracing, the actual stress values at elevations -21, -50, and -79.5 are 17.85 N/m<sup>2</sup>, 34.14 N/m<sup>2</sup>, and 20.78 N/m<sup>2</sup>, respectively. These values compare favourably to the corresponding allowable stresses, resulting in UC Ratios below unity at all elevations.

The UC ratio results reveal clear differences in structural utilization among the four bracing configurations. X-bracing consistently exhibits lower UC ratios across the structure, indicating more efficient load redistribution and higher redundancy. UC ratios approaching unity indicate reduced reserve capacity and smaller safety margins, emphasizing the importance of efficient bracing selection in preliminary design. A larger proportion of members in the X-braced model operate within low utilization ranges, reflecting effective structural performance.

In contrast, V- and diagonal bracing systems show higher UC ratios, particularly at lower elevations where environmental loads are dominant. This behavior is attributed to less effective load paths and limited alternate force redistribution mechanisms. K-bracing demonstrates intermediate performance, benefiting from reduced joint congestion but exhibiting localized higher utilization in compression-dominated members.

Table 4: The Axial Stress Result Data by Elevation

		ELEVATION					
		EL-21		EL-50		EL-79.5	
		Actual (N/m <sup>2</sup> )	Allowable(N/m <sup>2</sup> )	Actual(N/m <sup>2</sup> )	Allowable(N/m <sup>2</sup> )	Actual(N/m <sup>2</sup> )	Allowable(N/m <sup>2</sup> )
TYPES OF BRACING	DIAGONAL BRACING	71.25	198.35	88.45	198.35	57.45	198.35
	X-BRACING	17.85	159.52	34.14	115.72	20.78	143.07
	V-BRACING	47.37	198.35	117.59	45.83	46.88	86.73
	K-BRACING	123.49	47.81	85.26	198.35	115	57.36

Axial stress results indicate that stress demand generally increases toward lower elevations due to cumulative gravity and environmental load effects. X-bracing shows more uniform stress distribution along the height of the jacket, while V- and diagonal bracing systems experience higher stress concentrations at specific elevations. These findings highlight the influence of bracing geometry on load transfer mechanisms and member demand.

From a sustainability perspective, bracing systems that achieve lower UC ratios with fewer or more efficiently utilized members contribute to reduced material demand and improved structural efficiency. The superior performance of X-bracing suggests its suitability for sustainable offshore jacket design, particularly where material optimization and long-term structural reliability are critical.

## 5. CONCLUSIONS

This study presented a comparative linear static analysis of four offshore jacket bracing configurations using SACS, consistent with numerical analysis approaches widely applied in offshore structural studies (Motlagh *et al.*, 2021; National Ocean Industries Association, 2019). The results demonstrate that bracing configuration has a significant influence on structural utilization, axial stress distribution, and overall efficiency. Among the configurations studied, X-bracing exhibited the most favorable performance, characterized by lower UC ratios, more uniform stress distribution, and enhanced redundancy. V- and diagonal bracing systems showed higher member utilization, particularly at lower elevations, indicating reduced structural efficiency.

The findings confirm that informed bracing selection can enhance structural safety while reducing material demand, supporting sustainable offshore structural systems. The outcomes of this study provide practical guidance for preliminary jacket design and optimization. Future work should extend the analysis to include nonlinear behavior, soil–structure interaction, and life-cycle sustainability assessment.

## DATA AVAILABILITY STATEMENT

The data that support this study are available from the corresponding author upon reasonable request.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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