

## Optimized Bracing Configuration Analysis for Offshore Steel Fixed Jacket Platforms under Combined Environmental Loads

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### Abstract

The offshore steel fixed jacket platform is an important structural system that supports exploration and production processes in rough sea environment. The changing and difficult environmental loads, including wind, waves, currents and seismic forces, have been made difficult and complex by these platforms, which also affect the stability and long-term performance significantly. The use of bracing systems is important in augmenting the lateral stiffness, load distribution, and structural deformations in offshore jackets. The paper discusses the structural behaviour of offshore steel fixed jackets platform on bracing with different bracing arrangements in SAP 2000. A comprehensive finite element model has been created with realistic material characteristics, geometrical characteristics and load combinations with environmental loads as per standard design codes. The two analyses performed were a static and dynamic analysis to establish the displacement, base shear, stress distribution, natural frequency and overall stiffness under the combined environmental loading. The comparative analysis indicated that some of the layouts had considerable differences in the performance of the various bracing layouts with certain layouts being more resistant to deformation and stability. The paper highlights the importance of selecting the most appropriate bracing system to enhance the safety, reliability and efficiency of jacket platforms. The findings can be applied in the optimization of design and design of offshore structural engineering practice.

**Keywords:** Offshore jacket platform, bracing configuration, SAP 2000 analysis, environmental loads, dynamic behaviour, structural optimization.

### 1. Introduction

The oil and gas industry of the world relies on the offshore steel fixed jacket platforms as a stable platform to drill, extract and produce oil and gas within the marine ecosystem [1] [2]. These systems are well established on the seabed in terms of tubular steel piles and are engineered to work safely due to the combined forces of the environmental and operational forces. The jacket structure, which is made up of interconnected tubular steel structures, gives the necessary stiffness and stability to support heavy topside facilities and withstand extreme offshore conditions [3]. With the increasing levels of offshore exploration into more hostile and deeper waters, the need to have structurally efficient and robust jacket platforms has become more prominent [4], which has required the use of advanced analysis techniques, as well as optimization of structural design solutions. One of the greatest problems with offshore structural engineering is the difficulty in computing the loads on the platform during the lifetime of its operation [5]. These loads are wave forces, wind pressures, current actions, seismic forces, and operational loads, and accidental loads. All of these loads are of varying magnitude, direction and frequency meaning that the process of load analysis is very complex [6]. Dynamic effects induced by environmental forces, such as the wave and seismic loads can have a dramatic effect on the displacement of the platform [7], the vibration characteristics, and the internal force distribution. Not analyzing these loads correctly can cause structural instability, excessive deformations or even disastrous collapse. Extensive load analysis is therefore the basis of the assurance of the strength, safety and long-term performance of offshore jacket platforms.

The bracing systems have a very significant component in jackets platforms which has a significant impact on the lateral stiffness [8], strength and efficiency of load distribution of the jacket. Several types of bracing like X-bracing, K-bracing, V-bracing and knee bracing are tactically included in the jacket structure to oppose the horizontal forces and decrease the unbraced length of the vertical members [9]. Bracing has also been found to improve global stability, and less stress concentrations on the vital joints, increasing fatigue performance in the harsh marine environment [10]. The dynamic behaviour, natural frequency, displacement response and base shear capacity of the platform directly depend on the configuration of bracing [11]. There is therefore a need to carry out the analysis of the behavior of different bracing systems under the loaded conditions with the aim of optimizing the design. The analysis and design of offshore steel jackets platforms has been revolutionized by advanced computer assisted tools such as SAP 2000. Structural geometry interaction, material nonlinearities, soil structure and intricate environmental loading can be elaborated with the use of SAP 2000. By incorporating the approach of a static analysis and a dynamic analysis, such as the Equivalent Static Analysis (ESA), the Response Spectrum Analysis (RSA) and the time-history analysis, the engineers can ensure that the model that represents the real situation in the world becomes very precise. These types of analysis tools enable the development of effective patterns of bracing, high-quality load path and effective structural layout to achieve greater safety and cost-effectiveness. In conclusion, load analysis and bracing performance in offshore steel fixed jacket platforms is crucial in researching stability, durability and reliability of these structures in adverse marine conditions. The research has given rise to the offshore structural engineering since it has evaluated the effectiveness of bracing, critical loads influence and proposed the optimum design using SAP 2000.

### Comprehensive Load Analysis of Offshore Platforms



**Fig 1.** Comprehensive Load Analysis of Offshore Platforms

Sustainability and economic feasibility of offshore jacket platforms besides structural efficiency have now taken a major role in the current engineering practice. Determining the best bracing arrangement is not only a step towards improving structural stability, but also helps in optimization of the materials and minimization of expenditure by minimizing the quantity of steel that is not required to be utilized. In addition, the improvement in the modelling and simulation tools, has allowed the engineers to conduct more parametric studies, which has provided the engineers with a chance to predict the structural performance under different environmental conditions, in a more efficient way. This mix of novel methods of analysis and realistic design is here to ensure that offshore platforms are safe, reliable and flexible to the requirements of operation in the future in still more demanding marine environments.

**Neeta Chavhan et.al (2019)** Analysis of Offshore Structure Having Different Bracing Pattern Using Sap2000 Offshore fixed jacket platforms in 30 200 m waters experience complicated environmental forces, nonlinear wave forces being the most important. The correct modeling of these nonlinear effects is essential in availing stability in moderate and extreme conditions. Although the traditional allowable-stress approach is widespread, there are increasingly more demanding and rigorous constructions that are increasingly requiring the dynamic analysis to reflect time-sensitive reaction and ensure structural safety in the long-term [12]. **Gande Sandhya (2018)** Analysis of Offshore Jacket Structure Offshore fixed jacket platforms in 30200 m waters are subjected to very complex environmental loads with the biggest ones being nonlinear wave forces. Stresses, deformation and global stability are affected by severe sea states and nonlinear wave simulation is needed with high accuracy. Whereas allowable-stress and static approaches are applicable to rigid structures, more flexible and deep platforms need dynamic analysis of time (responses) and to guarantee efficient safe design [13]. **Yousuf Ahmed and Kumar (2019)** Seismic Behaviour of Offshore Steel Jacket Platform Braced in Horizontal and Vertical plane: Offshore jacket platforms are key in oil extraction and generation of energy and seismic performance analysis is paramount. Recent investigations point at effect of bracing systems on vibration control during earthquake and wave loads. SAP2000 v20 was used to model eight bracing configurations using ESA and RSA. The findings indicate that Inverted V bracing in vertical plane is better in its performance as it reduces the deck displacement and base shear [14].

**Supriya and Abhilash (2024)** Evaluation of Bracing Structures in Offshore Structures under Multi-Load Conditions Offshore structures are subjected to the forces of gravity, wind and seismic forces and therefore the selection of bracing configuration is important. This paper will compare the single, double and knee bracing at 0deg, 20deg and 30deg using FEM and time-history analysis in SAP2000. Findings indicate that knee bracing (compared to double bracing at 30 degrees) provides better stability and frequency performance and steeper angles (30 degrees) give optimum base-shear and displacement resistance, and the overall structural behaviour is better with higher angles [15]. **Shehata E. and Abdel Raheem (2013)** Nonlinear offshore platform response to structural and wave loading: Fixed jacket offshore platform The design of offshore platforms is highly sensitive to the waves, and the forces caused by them, which necessitates nonlinear estimation of loads to ensure safety and cost-effectiveness. Nonlinear responses to structural, wave, and current actions are calculated using FEM, 5th-order Stokes theory, and the Morison equation. The 1-year operational and 100-year extreme waves are evaluated in terms of displacements and internal forces. The results prove that nonlinear analysis is a key to ensuring the reliable operation and existence of offshore platforms [16].

**2. Materials and Methodology**

**2.1 Methodology**

The study methodology has been designed in such a way that it provides a systematic way of examining structural behaviour of offshore steel fixed jacket platforms loaded with a combination of environments with various bracing arrangements.

The study starts with the creation of a realistic three-dimensional finite element model in the SAP2000 system and the use of offshore-grade circular hollow steel sections (CHS) according to API RP 2A and ISO 19902 specifications. The model geometry was established upon realistic jacket dimensions, the leg spacing, the connection between the braces and the deck framing. Pile-leg fixity was modelled to provide some of the conditions of seabed restraint that can be experienced in offshore environment as the boundary conditions. Design codes that were internationally recognized were used to compute environmental loads.

**2.2 Materials and Methods**

The equation by Morison was used to establish the wave forces with consideration of the components of drag and inertia in the changing sea states. Wind loads were considered based on the provisions of IS 875, and the seismic actions were considered based on the provisions of IS 1893 based on the response spectrum and modal parameters. The loads that existed, such as current loads, dead loads, and live loads, were also incorporated to provide a simulation of the operational and environmental conditions. To investigate the dynamic response during real seismic activity, a time-history ground motion input, namely the BHUJ earthquake record was included.



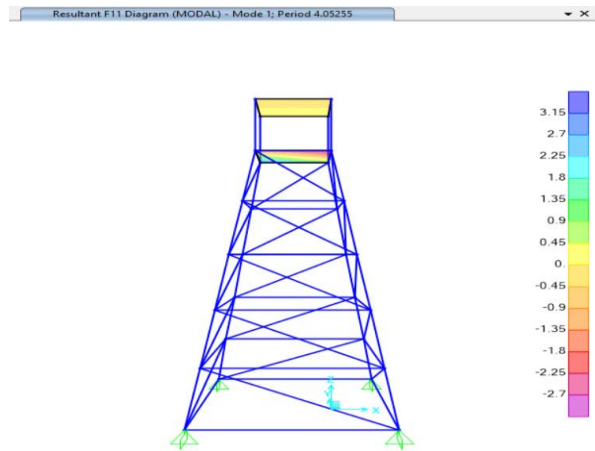
**Fig 2.** Flowchart

**Table 1:** Materials and Methods Used in the Study

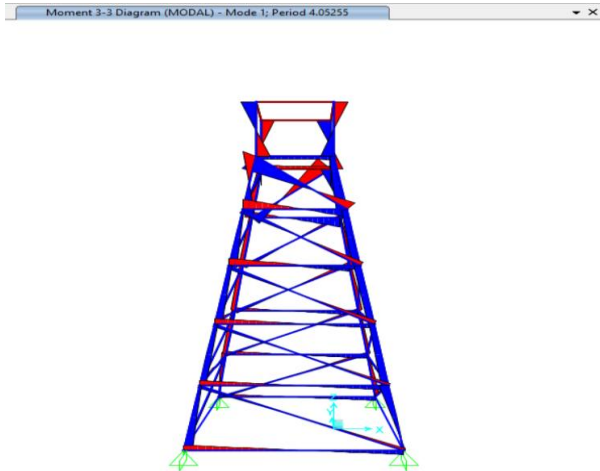
Item	Description
Materials (Steel & Sections)	Offshore-grade structural steel (API RP 2A / ISO 19902) and circular hollow sections (CHS) used for jacket legs, braces, and horizontal members.
Software Used	SAP 2000 software used for 3D modelling, load application, static analysis, and dynamic analysis of the jacket platform.
Environmental Load Data	Wind, wave, current, and seismic load parameters collected from API standards, IS 875, IS 1893, and Morison's equation.
Model Development Method	3D finite element model created in SAP 2000 with assigned material properties, section properties, supports, and bracing configurations.
Load Application Method	Dead load, live load, wave load, wind load, current load, and seismic load applied using standard codal load combinations.
Static & Dynamic Analysis	Static analysis for displacement/stress and dynamic analysis (modal & response spectrum) performed to evaluate structural performance.
Performance Evaluation	Displacement, base shear, stress ratio, and stiffness compared for different bracing types to identify the optimal configuration.

**3. Results and Discussion**

The analysis results indicate that there are considerable variations in the structural performance of offshore steel fixed jacket platforms with various bracing systems subjected to combined environmental loads. The displacement of both 0 and 30 degrees suggests that there is a significant decrease in deformation when using both braces than when using single braces and knee braces behaves better in the dynamic loading conditions. Knee bracing is also found to have better load distribution and deformation resistance as shown by base shear and stress analysis. The findings highlight the importance of selecting the appropriate bracing system to portray the greatest platform stability, reduced material usage, and the general security in harsh marine environment.

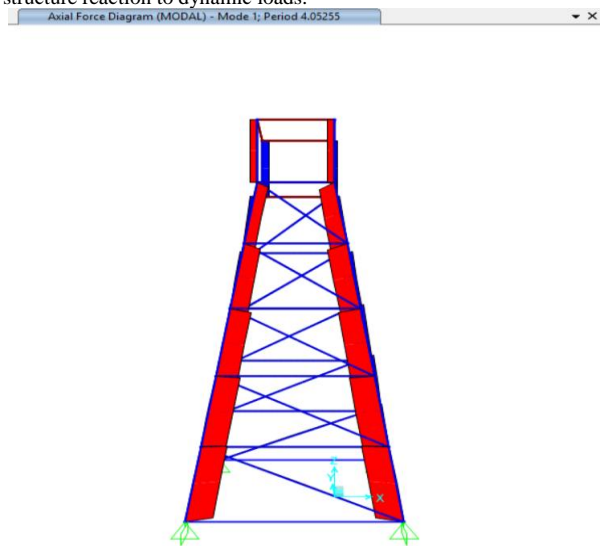


**Fig 3.** Modal Analysis Resultant F11 Diagram for Offshore Jacket Platform The first mode shape of the offshore jacket platform in the modal analysis is shown in the diagram. The period of the displacement of the platform is 4.05255 seconds and F11 represents the resultant forces. The magnitude of the forces is the color gradient: the larger the number, the higher the position in the structure and the more the dynamic behaviour of the platform as the loads are applied.



**Fig 4.** Modal Moment 3-3 Diagram for Offshore Jacket Platform

This is the first mode shape of offshore jacket platform which illustrates the distribution of moment (3-3 direction) when doing the modal analysis. The diagram done in color depicts the moment forces on the members of the platform with the red and blue color indicating the magnitude and direction of the moment. The analysis provides the understanding of the stability of the platform, and structure reaction to dynamic loads.



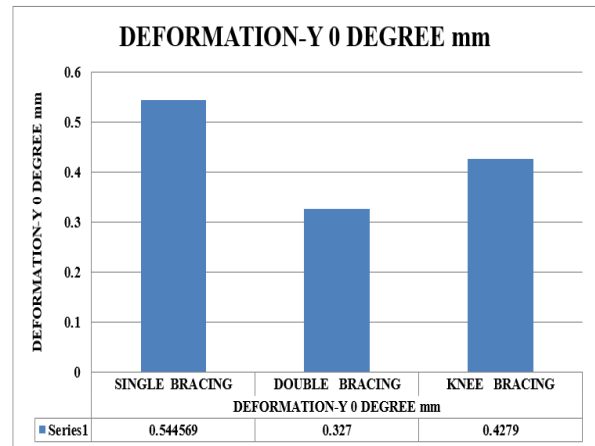
**Fig 5.** Modal Axial Force Diagram for Offshore Jacket Platform

The distribution of the axial forces along the offshore jacket platform during the first mode of vibration is illustrated by this diagram. The red areas depict the largest axial forces whereas the blue areas depict the least. The axial forces play a vital role in the analysis of the structural response of the platform to dynamic load, and they are used to optimize the design of the platform.

The table shows the deformation values for three different bracing systems under 0° displacement. The deformation of single bracing is greatest (0.544569 mm), then knee bracing (0.4279 mm), and finally, the deformation of double bracing (0.327 mm) is the least, which implies that the double bracing is the best in terms of resistance to displacement.

**Table 2:** Displacement 0 Degree

Deformation-Y 0 Degree mm		
Single Bracing	Double Bracing	Knee Bracing
0.544569	0.327	0.4279



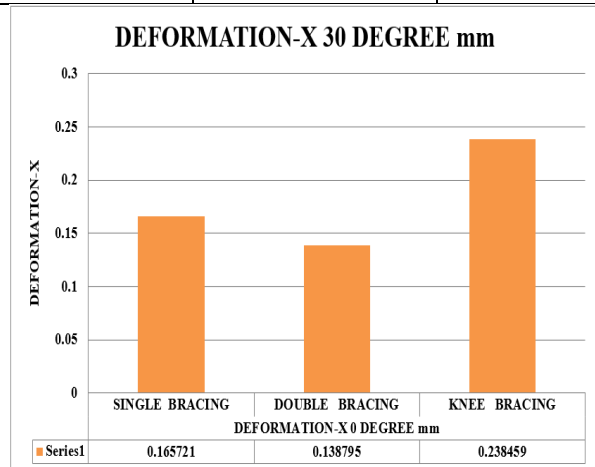
**Fig 6.** Deformation-Y 0 Degree mm for Different Bracing Configurations

The bar chart shows the deformation at 0° of three bracing configurations. It has highest deformation of single bracing of 0.544569 mm, then the knee bracing of 0.4279 mm, and lastly the double bracing with the lowest deformation of 0.327 mm. This means that the resistance to displacement below 0° conditions is maximum when using double bracing.

The table indicates the values of deformation of three bracing systems at 30° X-direction displacement. The deformation of single bracing is the least (0.165721 mm), then double bracing (0.138795 mm) and knee bracing (0.238459 mm) has the highest deformation. This emphasizes that in this direction, the best resistance is provided by the double bracing.

**Table 3:** Displacement 30 Degree for X Direction

Deformation-X 30 Degree Mm		
Single Bracing	Double Bracing	Knee Bracing
0.165721	0.138795	0.238459



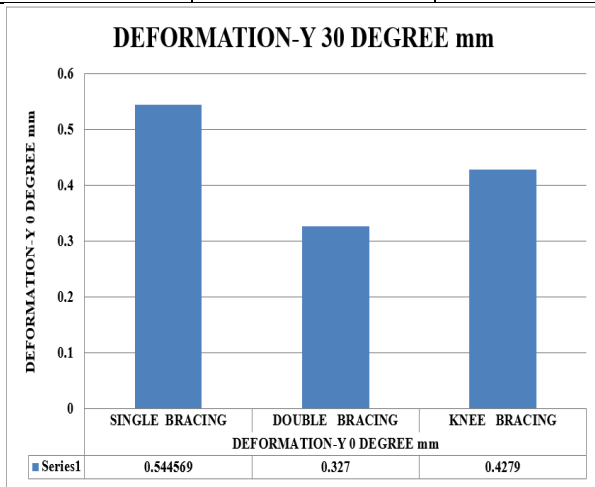
**Fig 7.** Deformation-X 30 Degree mm for Different Bracing Configurations

The deformation at 30 degrees in the X direction of the bar chart is the deformation of three bracing configurations. The deformation of single bracing is the least at 0.165721 mm and double bracing is the least with deformation of 0.138795 mm and knee bracing has the highest deformation of 0.238459 mm.

The table shows the deformation values of three bracing designs with the 30° displacement in the Y direction. The deformation of single bracing is the highest with a deformation of 0.544569 mm and then the deformation of knee bracing is 0.4279 mm and the deformation of the double bracing is the least with 0.327 mm deformation. This implies that the bracing type that offers the best resistance to the Y direction is double bracing.

**Table 4:** Displacement 30 Degree for Y Direction

Deformation-Y 30 Degree mm		
Single Bracing	Double Bracing	Knee Bracing
0.544569	0.327	0.4279



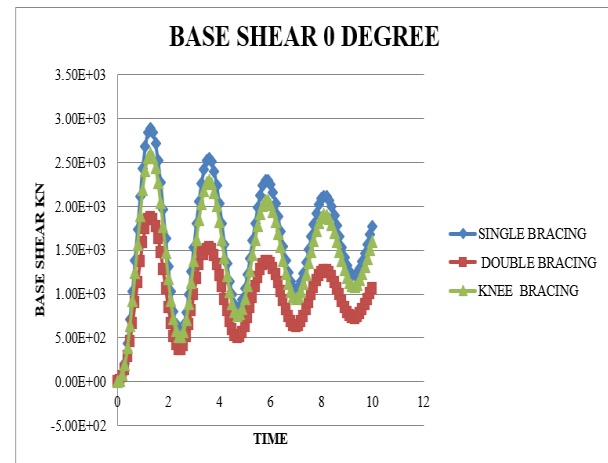
**Fig 8.** Deformation-Y 30 Degree mm for Different Bracing Configurations

The bar chart indicates the deformation in the Y direction at 30o in three bracing layouts. Single bracing has the greatest deformation of 0.544569 mm, then knee bracing has 0.4279 mm and lastly, the least deformation of 0.327 mm by double bracing.

The table displays the values of the base shear of three bracing arrangements at various time intervals under 0 conditions. Single bracing has the maximum base shear (4.38E-04) at time 0, whereas the lowest base shear (2.85E-04) is found at time 0 in double bracing. Over time, single bracing will always record the greatest base shear values, whereas knee bracing will provide an intermediate and double bracing the least base shear values in the measurements. At time 10, the values of single bracing, double bracing and knee bracing are 1774.687, 1060 and 1600 respectively, indicating that double bracing is the most resistant.

**Table 5:** Base Shear 0 Degree

Time	Single Bracing	Double Bracing	Knee Bracing
0	4.38E-04	2.85E-04	3.94E-04
1	2434.439	1.58E+03	2.19E+03
2	1310.233	8.52E+02	1.18E+03
3	1531.529	9.95E+02	1.38E+03
4	2027.247	1.22E+03	1.82E+03
5	1057.419	6.34E+02	9.52E+02
6	2250.103	1.35E+03	2.03E+03
7	1054.735	6.33E+02	9.94E+02
8	2084.699	1.25E+03	1.88E+03
9	1323.426	7.94E+02	1.19E+03
10	1774.687	1.06E+03	1.60E+03



**Fig 9.** Base Shear 0 Degree for Different Bracing Configurations

The graph shows the base shear (in kN) versus time of three bracing arrangements at 0deg displacement. The highest base shear variation is observed in single bracing (blue), then knee bracing (green) and lastly, the least base shear response is observed in double bracing (red). This implies that double bracing is more stable and effective in distribution of load in the long run.

**4. Conclusion**

This paper examines structural behavior of offshore steel fixed jacket platforms with mixed environmental loads, and in particular, the behavior of various bracing arrangements. A detailed finite element model was created using SAP 2000 to model real-world conditions with wave, wind, seismic and current loads. The findings showed that knee bracing was the best when compared to single and double bracing insofar as displacement and base shear resistance were concerned especially when subjected to dynamic loading situations. Knee bracing showed a better ability to minimize deformation, and least displacement was at 0 and 30 degrees in the Y and X directions respectively. Knee bracing was also found to provide better load distribution and stress resistance that improved the overall stability of the platform and minimized the risk of structural failure. The necessity to select the right bracing system to optimise the materials and to be capable of guaranteeing the safety of the operations in the long-term was another aspect that was highlighted in the study. Although double bracing exhibited excellent behavior especially in minimizing the displacement, knee bracing had the most desirable overall structural response, which entails stability, distribution of loads and less deformation. The results are very crucial to design of offshore platforms optimization, enhancement of safety standards and minimization of costs of construction. The paper notes that more research is needed on the creation of more analytical and calculation methods to develop the offshore structural engineering and design capacity in the extreme environmental conditions. This research has a lot to offer towards optimization of offshore steel jacket platforms.

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