

Load Analysis of Offshore Steel Fixed Jacket Platform Structures Having Bracing Pattern

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Abstract

Offshore steel fixed jacket platforms are widely used in shallow and medium water-depth regions for oil and gas exploration, drilling and production operations. These platforms are continuously exposed to severe environmental actions such as wave load, wind load, current load and seismic excitation. The structural stability of such platforms depends greatly on the bracing configuration adopted in the jacket system. The present study focuses on the load analysis of an offshore steel fixed jacket platform with different bracing patterns using SAP2000. A four-legged fixed jacket platform is modelled and analysed under static and dynamic loading conditions. Three bracing systems, namely single bracing, double bracing and knee bracing, are considered at different inclination angles of 0°, 20° and 30°. The structural response is evaluated in terms of time period, base shear, natural frequency and displacement. The results indicate that bracing arrangement and bracing inclination significantly influence the stiffness, dynamic response and displacement behaviour of the offshore jacket platform. The comparative evaluation helps identify an efficient bracing system for improving structural stability, reducing deformation and enhancing safety under offshore environmental loading.

Keywords: Offshore jacket platform, SAP2000, bracing pattern, base shear, time period, natural frequency, displacement, dynamic analysis.

1. INTRODUCTION

Offshore steel fixed jacket platforms are important structural systems used in marine oil and gas exploration, production and drilling activities. These platforms are generally adopted in shallow to medium water depths because of their high lateral stability, strong seabed anchorage and efficient load transfer capacity. A fixed jacket platform mainly consists of tubular steel legs, horizontal and diagonal bracing members, piles and a topside deck arrangement. The structure is fixed to the seabed through piles, while the jacket framework resists vertical and lateral loads transferred from the deck, equipment and environmental actions. The safety and serviceability of such platforms are highly dependent on the structural configuration, member sizing, bracing pattern and dynamic characteristics of the system.

Unlike ordinary land-based structures, offshore platforms are subjected to complex environmental loads. These include wave forces, wind forces, current forces, seismic forces and operational loads. Wave loading is generally one of the most dominant actions on offshore structures because it produces time-dependent hydrodynamic forces on the tubular members. Wind forces act on exposed deck and topside components, while current loads produce additional horizontal drag on submerged members. In seismic-prone regions, earthquake excitation further increases the lateral demand on the platform. The combined action of these loads may cause displacement, vibration, member stress concentration and fatigue damage. Therefore, proper static and dynamic load analysis is necessary for ensuring structural integrity and long-term platform performance.

Bracing systems play a major role in improving the behaviour of offshore jacket structures. Braces connect the vertical jacket legs and help distribute lateral forces throughout the structure. They increase stiffness, reduce sway, control deformation and improve energy transfer during dynamic loading. Different bracing systems such as single bracing, double bracing, X-bracing, K-bracing, V-bracing and knee bracing are commonly used depending on the geometry, water depth, loading intensity and design requirement. The effectiveness of a bracing system depends not only on its type but also on its inclination angle, member size and connection arrangement. A poorly selected bracing configuration may lead to excessive displacement, high base shear or unfavourable dynamic response.

The present research studies a fixed offshore steel jacket platform by considering different bracing configurations. The platform is modelled using SAP2000, which is a finite-element-based structural analysis software capable of performing static and dynamic analysis of complex structures. SAP2000 allows modelling of tubular members, assignment of material properties, application of load cases and extraction of modal and response parameters. In this study, single bracing, double bracing and knee bracing systems are analysed at 0° , 20° and 30° orientations. The comparative performance is studied through time period, base shear, natural frequency and displacement results.

The motivation of the study is to understand how bracing configuration affects the structural performance of offshore fixed jacket platforms. Since offshore platforms are costly and safety-critical structures, optimization of bracing patterns can improve both structural safety and economic efficiency. A suitable bracing system can reduce deformation, improve stiffness and enhance resistance against dynamic loading. Therefore, this study provides a useful technical comparison for selecting efficient bracing systems for offshore jacket platforms.



Figure 1. Typical Offshore Jacket Platform Model

2. OBJECTIVES

The objectives are kept as given in the project report:

1. To evaluate the structural performance of offshore steel fixed jacket platforms with various bracing configurations.
2. To perform dynamic and static load analysis using SAP 2000.
3. To optimize bracing systems for minimizing displacement and base shear.
4. To assess the impact of environmental loads on platform stability.
5. To propose design improvements for enhanced structural integrity and safety.

3. SCOPE OF THE STUDY

The scope of the present study is limited to the structural analysis of a fixed offshore steel jacket platform with different bracing patterns. A four-legged jacket platform is selected and modelled using SAP2000. The study considers single bracing, double bracing and knee bracing systems at different angles of 0° , 20° and 30° . The performance of each model is evaluated under static and dynamic loading conditions. The key response parameters considered are time period, base shear, natural frequency and displacement. The study focuses on comparative structural behaviour and does not include detailed fatigue assessment, corrosion modelling, nonlinear collapse analysis or soil–structure interaction. However, the results provide a useful basis for selecting efficient bracing configurations for offshore platform stability and safety.

4. LITERATURE REVIEW

Neeta Chavhan et al. (2019) studied offshore structures with different bracing patterns using SAP2000. Their work highlighted the importance of environmental loads such as wind, wave, current and seismic forces in the design of fixed jacket platforms. The authors emphasized that offshore platforms are exposed to uncertain loading throughout their service life, and therefore accurate structural modelling is necessary for safe design. The study showed that bracing pattern has a significant effect on displacement and overall platform stability. Gande Sandhya (2018) analysed offshore jacket structures and discussed their role in oil and gas exploration. The study explained that fixed jacket platforms are generally used in shallow water and are supported by tubular piles driven into the seabed. The work focused on static analysis and load application using offshore structural software. It also emphasized that structural optimization is necessary because jacket structures are expensive and material-intensive. Yousuf Ahmed and Kumar (2019) investigated the seismic behaviour of offshore steel jacket platforms braced in horizontal and vertical planes. Their study included different bracing configurations such as X, V, inverted V and K bracing. The analysis was performed using SAP2000 under equivalent static and response spectrum methods. The results showed that bracing configuration significantly affects time period, displacement and base shear. Inverted V bracing in the vertical plane was reported as an efficient configuration for reducing displacement and base shear. Supriya and Abhilash (2024) evaluated bracing configurations in offshore structures under multiple load conditions. They considered single bracing, double bracing and knee bracing at 0°, 20° and 30° inclinations. The study assessed time period, base shear, natural frequency and displacement using finite element modelling and time history analysis. The results indicated that knee bracing provides improved dynamic response, while double bracing shows good displacement control under certain angular configurations.

Shehata and Abdel Raheem (2013) studied nonlinear response of fixed offshore platforms under structural and wave loading. Their analysis used finite element modelling, Morison's equation and fifth-order Stokes wave theory for hydrodynamic loading. The study confirmed that nonlinear response analysis is important for safe design and operation of offshore platforms, especially under extreme wave conditions. The research also highlighted that displacement, axial force and bending moment distribution are essential parameters for evaluating offshore structural safety. Juswan et al. (2020) investigated the influence of effective length and reduction factor on buckling of jacket braces. The authors noted that braces support the jacket structure both locally and globally against internal and external loads. They observed that brace length has a major influence on local buckling and global platform behaviour. Their study emphasized the need to check brace stability according to offshore design provisions such as API recommendations. Faseela and Jayalekshmi (2015) focused on in-place strength evaluation and optimization of bracing configurations in jacket platforms. They considered different bracing arrangements and compared their structural weight and stress performance. Their study indicated that selection of bracing configuration can reduce structural weight while maintaining adequate safety. The research supports the idea that bracing optimization is both a structural and economic requirement. Bipasha Das (2017) developed a model and performed load analysis of an offshore jacket structure using SAP2000. The study considered static and dynamic load cases such as wind, wave and earthquake loads. The results included displacement and bending moment responses. The work demonstrated that SAP2000 can be effectively used to predict the behaviour of jacket structures under multiple loading conditions.

Overall, the literature shows that offshore jacket platforms require careful evaluation under environmental loading. Previous studies have analysed various bracing systems; however, comparative assessment of single, double and knee bracing at different inclinations under the same modelling conditions remains important. The present study addresses this requirement by comparing time period, base shear, natural frequency and displacement responses of different bracing configurations using SAP2000.

5. RESEARCH GAP

From the literature review, it is observed that many studies have analysed offshore jacket platforms under wave, wind and seismic loading. Several researchers have also studied the influence of X, V, K, inverted V, single, double and knee bracing systems. However, most studies focus on either a limited number of bracing arrangements or individual loading effects. There is a need for a systematic comparative study in which the same offshore jacket platform is analysed with

different bracing patterns and bracing angles under identical modelling assumptions. Another gap is related to the combined interpretation of dynamic parameters. Many studies report displacement or base shear separately, but fewer studies compare time period, base shear, natural frequency and displacement together for the same set of models. Since offshore platforms are dynamic systems, time period and natural frequency are equally important along with displacement and base shear. The present study therefore compares single, double and knee bracing systems at 0° , 20° and 30° to identify the most efficient bracing pattern for improved offshore platform stability.

6. METHODOLOGY

The methodology adopted in this research is based on finite element modelling and load analysis of an offshore steel fixed jacket platform using SAP2000. The overall process includes selection of platform geometry, definition of material properties, development of bracing models, application of loads, execution of static and dynamic analysis, extraction of results and comparative evaluation.

6.1 Platform Selection and Geometry

A fixed jacket-type offshore platform is selected for the study. The platform consists of four legs, four piles and a topside deck system. The jacket is nearly 136 ft deep and is made of steel tubular members. The structure represents a typical offshore jacket platform suitable for shallow to medium water depth. The topside arrangement includes a production deck and helideck, while the jacket frame transfers loads to the seabed through piles. The platform is modelled as a three-dimensional steel tubular-space frame.

6.2 Bracing Configurations

Nine analytical models are prepared for comparative analysis. The same platform geometry and material properties are used in all models to ensure accuracy and fair comparison. The models differ only in bracing configuration and bracing inclination. The configurations considered are:

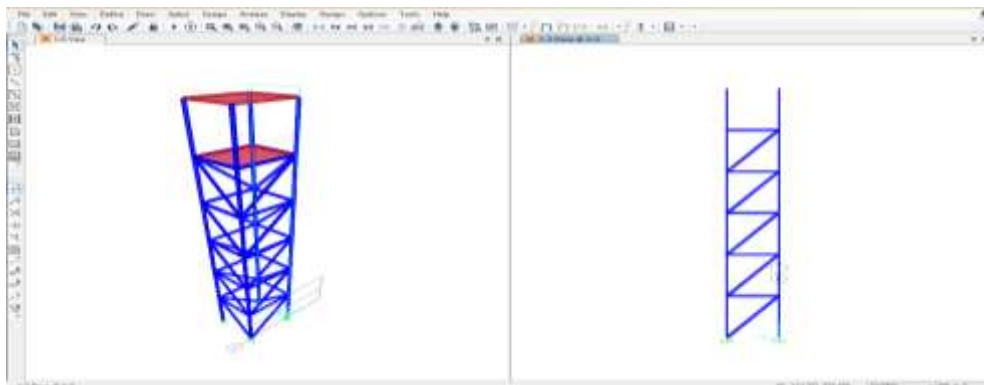


Figure 2. Double Bracing 0°

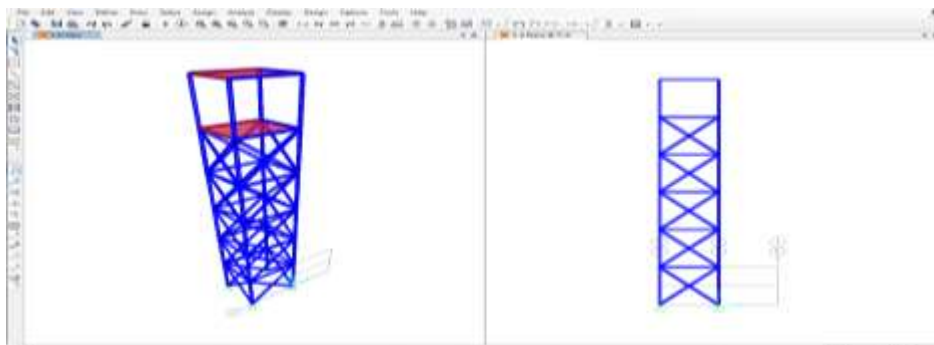


Figure 3. Knee Bracing 0°

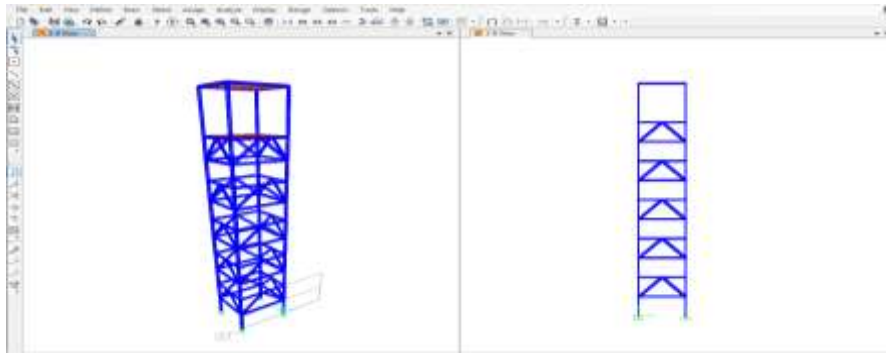


Figure 4. Single, Double and Knee Bracing at 20° and 30°

6.3 Material Properties and Loading

Structural steel is used for modelling the jacket platform. The density values considered include concrete as 25 kN/m³, insulation as 1 kN/m³ and structural steel as 78.5 kN/m³. The live load is considered as 5 kN/m³. Wind load is applied using a basic wind speed of 55 m/s, terrain category 2, class of structure C, risk coefficient k₁ as 1 and topography factor k₃ as 1. Earthquake loading is considered according to IS 1893 provisions, with zone factor 0.16, seismic Zone III, importance factor 1.5 and response reduction factor 3.

6.4 Static and Dynamic Analysis

Static analysis is performed to determine the response of the platform under steady loads such as self-weight, live load and environmental load components. Dynamic analysis is performed to evaluate time period, natural frequency and response characteristics of the braced jacket platform. Response spectrum and time-history concepts are used to understand seismic behaviour. The total design base shear is considered using the relation:

$$V_b = A_h \times W$$

where V_b is the design base shear, A_h is the design horizontal seismic coefficient and W is the seismic weight of the structure.

6.5 Result Extraction

After analysis, the results are extracted for time period, base shear, natural frequency and displacement. These parameters are selected because they directly indicate structural stiffness, dynamic stability and deformation control. Time period reflects the flexibility of the system. Base shear indicates seismic force demand. Natural frequency shows vibration characteristics. Displacement indicates the deformation response of the structure.

6.6 Comparative Evaluation

The extracted results are compared for single, double and knee bracing systems at 0°, 20° and 30°. The comparison is used to identify which bracing system provides better stiffness, lower displacement and improved stability. The final conclusions are drawn based on the overall performance of all bracing models.

7. RESULTS AND DISCUSSION

7.1 Time Period at 0° Bracing

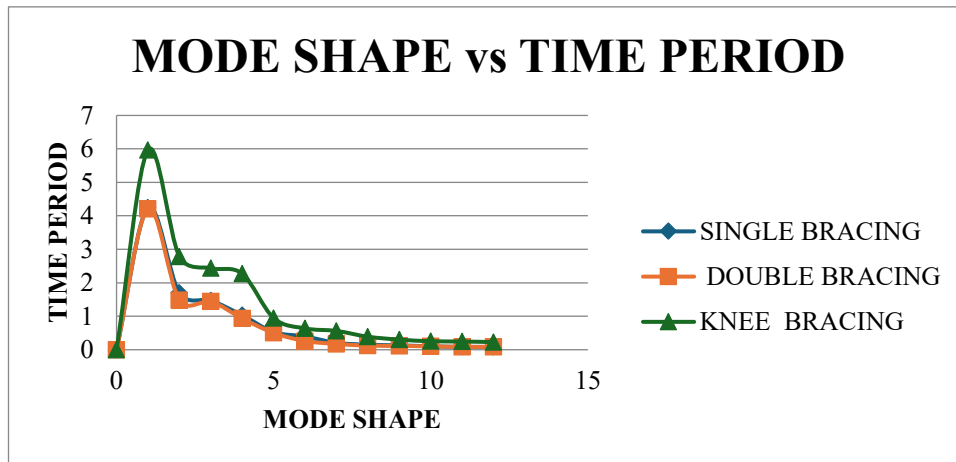


Figure 5. Mode Shape vs Time Period for 0° Bracing

The results show that knee bracing gives the highest time period in the first mode, with a value of 5.963801 sec. Single bracing gives 4.24472 sec, while double bracing gives 4.209284 sec. A higher time period indicates higher flexibility of the structure. Therefore, at 0° orientation, knee bracing shows comparatively more flexible behaviour, whereas double bracing gives comparatively lower time period and higher stiffness.

7.2 Time Period at 20° Bracing

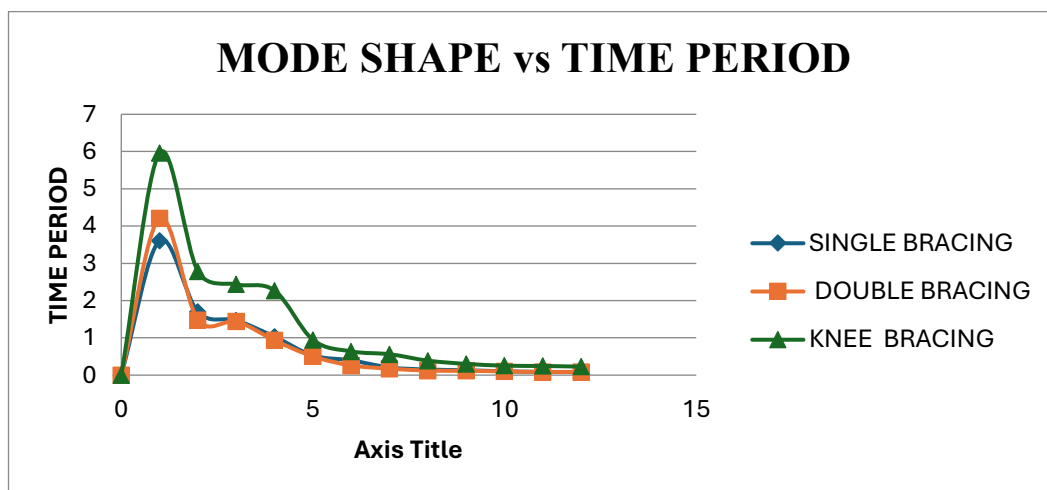


Figure 6. Mode Shape vs Time Period for 20° Bracing

At 20° bracing inclination, knee bracing again shows the maximum first-mode time period of 5.963801 sec. Single bracing reduces to 3.608012 sec, indicating improved stiffness compared with the 0° single bracing model. Double bracing remains at 4.209284 sec. This shows that bracing angle affects the time period, particularly in the single bracing model.

7.3 Time Period at 30° Bracing

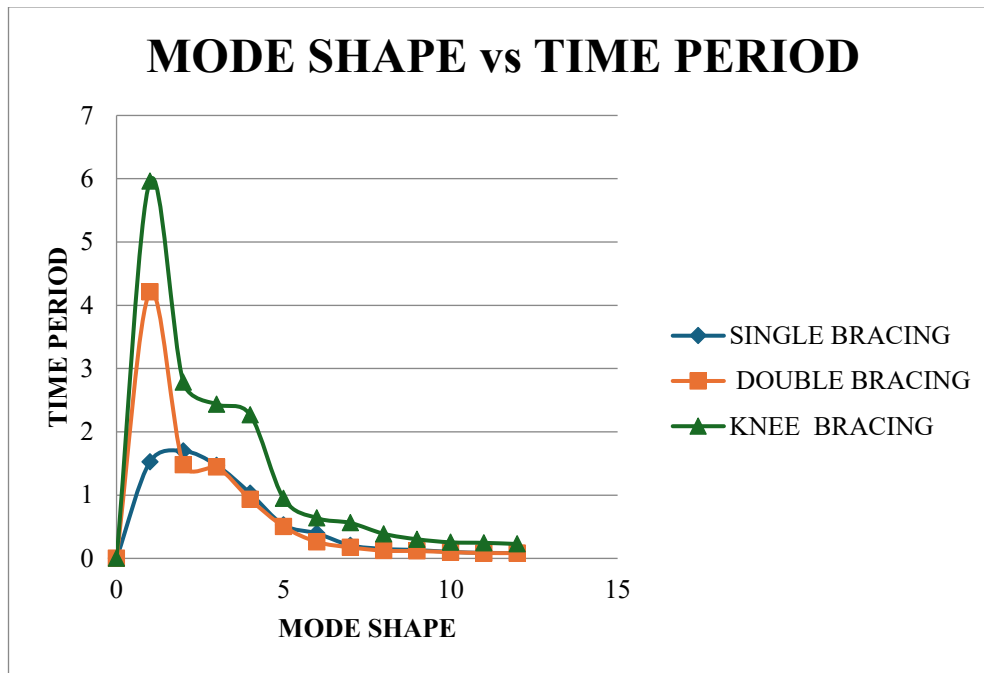


Figure 7. Mode Shape vs Time Period for 30° Bracing

At 30° bracing inclination, single bracing shows a major reduction in first-mode time period to 1.526913 sec. This indicates that the 30° single bracing arrangement improves stiffness significantly compared with the 0° and 20° cases. Knee bracing continues to show the highest time period, indicating flexible response. Therefore, the angle of bracing has a strong influence on the dynamic characteristics of the platform.

7.4 Base Shear Response

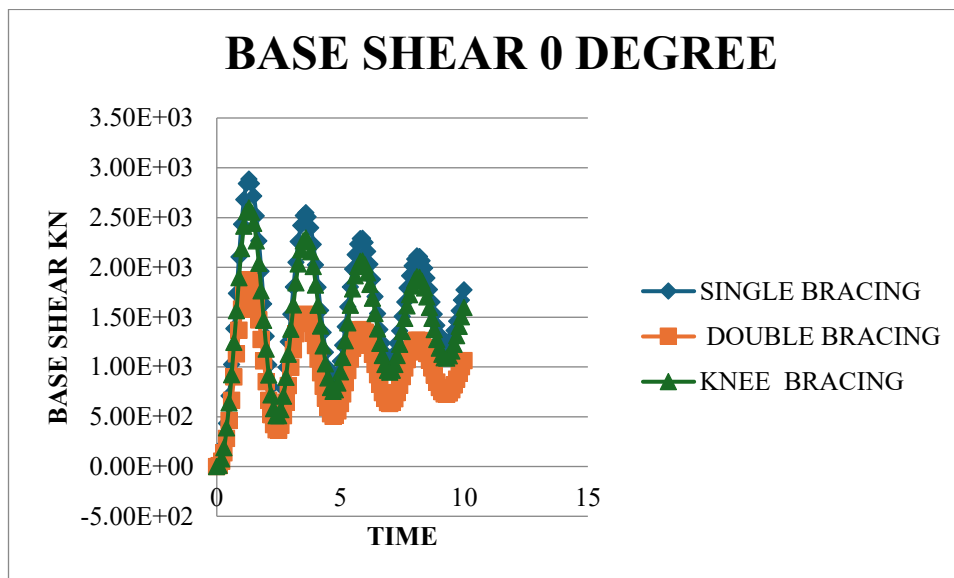


Figure 8. Base Shear vs Time Period

The base shear results show that the maximum base shear occurs at approximately 1.3 sec. The maximum absolute base shear values are approximately 2886.26898 for single bracing, 1880 for double bracing and 2600 for knee bracing. The single bracing model shows the highest base shear demand, while double bracing shows the lowest among the three systems. This indicates that double bracing provides better control of seismic force demand in comparison with single and knee bracing.

7.5 Natural Frequency Results

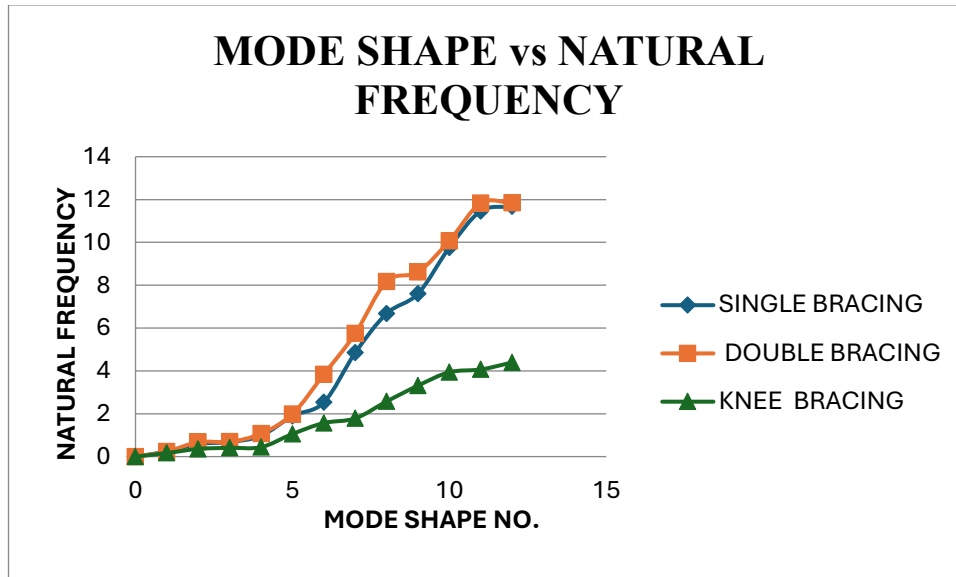


Figure 9. Mode Shape vs Natural Frequency

The natural frequency results show that double bracing generally provides the highest natural frequency values in higher modes. This indicates that double bracing increases the stiffness of the platform and improves dynamic stability. Knee bracing gives lower natural frequency values, particularly in the first mode, which corresponds to its higher time period. The inverse relationship between time period and natural frequency is clearly observed in the results.

7.6 Displacement and Deformation Results

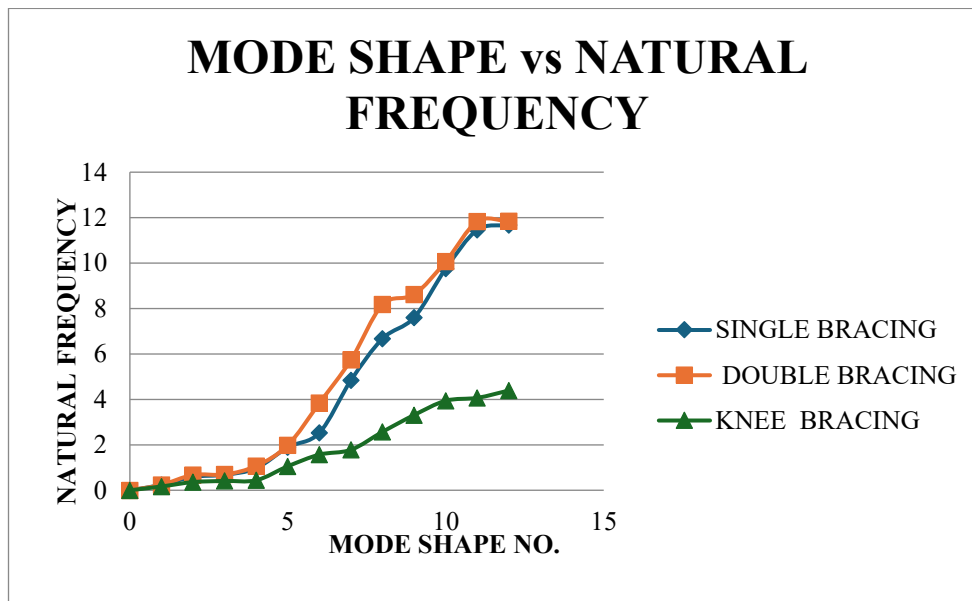


Figure 10. Displacement and Deformation Results

The displacement results show that double bracing provides the lowest deformation in all listed cases. For Y-direction deformation at 0°, 20° and 30°, double bracing gives 0.327 mm, which is lower than single bracing at 0.544569 mm and knee bracing at 0.4279 mm. For X-direction deformation at 20° and 30°, double bracing gives 0.138795 mm, which is lower than single bracing at 0.165721 mm and knee bracing at 0.238459 mm. This confirms that double bracing is more effective in controlling displacement and improving lateral stiffness.

DISPLACEMENT 0 DEGREE

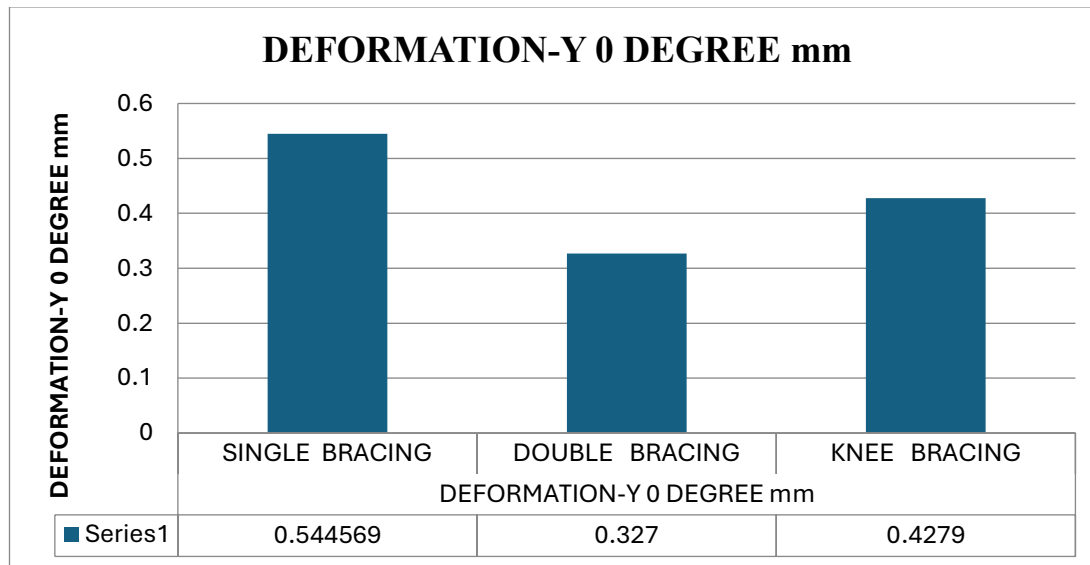


Figure 11: Displacement 0 Degree

In this graph maximum deformation-y 0 degree is in single bracing is 0.52. The difference between single and knee bracing is 25%.

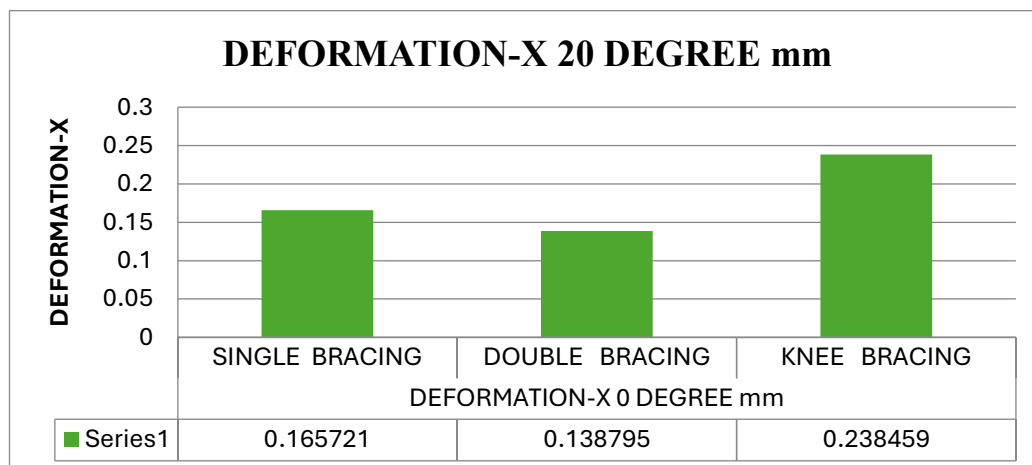


Figure 12: Deformation-X20 Degree

In this graph maximum deformation-x 20 degree is in knee bracing is 0.24. The difference between single and knee bracing is 30%.

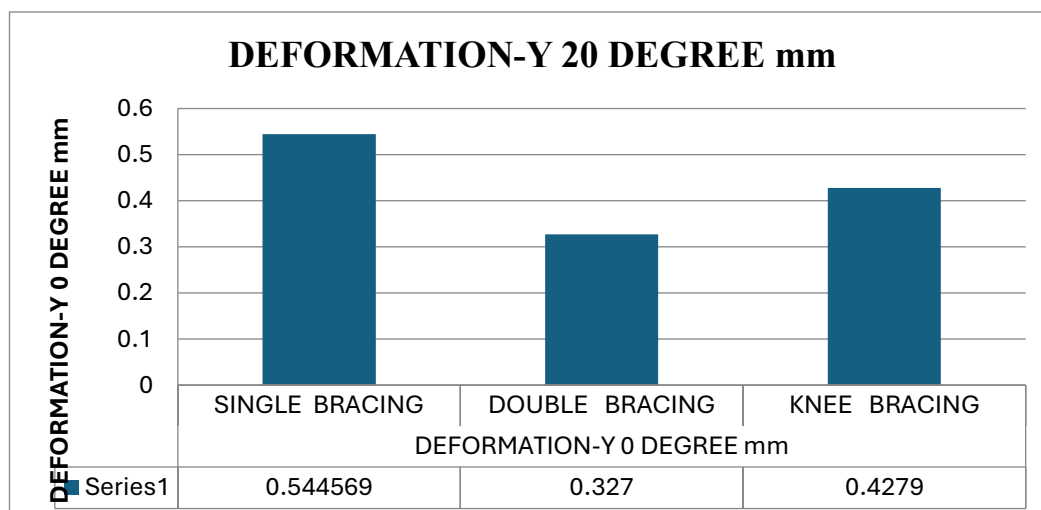


Figure 13: Deformation-Y20 Degree

In this graph maximum deformation-y 20 degree is in single bracing is 0.52. The difference between single and knee bracing is 25%.

8. DISCUSSION

The comparative study of single, double and knee bracing systems indicates that bracing configuration has a major influence on offshore jacket platform behaviour. Time period results show that knee bracing produces the highest first-mode time period at all considered angles. This indicates that the knee bracing model is more flexible compared with the single and double bracing systems. A higher time period may reduce some acceleration response, but it may also increase displacement demand under certain dynamic conditions. Therefore, knee bracing requires careful evaluation when used in offshore jacket platforms.

Single bracing shows variable behaviour with changing bracing angle. At 0° , the first-mode time period is 4.24472 sec. At 20° , it reduces to 3.608012 sec, and at 30° , it reduces sharply to 1.526913 sec. This indicates that increasing the bracing angle improves stiffness in the single bracing system. However, the base shear results show that single bracing develops the highest maximum base shear, which may increase demand on foundation and lower jacket members.

Double bracing provides stable and efficient behaviour. It shows relatively lower time period compared with knee bracing and also produces the lowest maximum base shear among the three bracing systems. The displacement results also confirm that double bracing gives the least deformation in both X and Y directions. This suggests that double bracing improves stiffness, controls displacement and reduces seismic force demand more effectively than the other systems.

Natural frequency results further support this interpretation. Double bracing generally shows higher frequency values in higher modes, indicating increased stiffness and improved vibration control. Knee bracing shows lower frequency values and higher time period, confirming comparatively flexible behaviour. Therefore, considering time period, base shear, natural frequency and displacement together, double bracing appears to be the most efficient bracing configuration among the analysed systems.

9. CONCLUSION

The present study evaluates the structural behaviour of an offshore steel fixed jacket platform with different bracing configurations using SAP2000. The analysis considers single bracing, double bracing and knee bracing at 0° , 20° and 30° inclinations. Based on the obtained results, the following conclusions are drawn:

1. Bracing configuration has a significant effect on the dynamic and static performance of offshore jacket platforms.
2. Knee bracing shows the highest first-mode time period, with a maximum value of 5.963801 sec, indicating comparatively flexible structural behaviour.
3. Single bracing shows considerable improvement in stiffness when the bracing angle is increased from 0° to 30° , as its first-mode time period reduces from 4.24472 sec to 1.526913 sec.
4. Base shear results show that single bracing develops the highest maximum base shear of about 2886.26898, while double bracing shows the lowest maximum base shear of about 1880.
5. Natural frequency results indicate that double bracing provides higher frequency response in several modes, reflecting improved stiffness and better dynamic stability.
6. Displacement results show that double bracing provides the least deformation in both X and Y directions. The Y-direction deformation for double bracing is 0.327 mm, compared with 0.544569 mm for single bracing and 0.4279 mm for knee bracing.
7. Considering base shear reduction, displacement control and dynamic stability, double bracing is found to be the most efficient configuration among the studied bracing systems.

8. The study confirms that proper selection of bracing pattern and bracing angle is essential for improving the structural integrity, safety and performance of offshore steel fixed jacket platforms.

10. FUTURE SCOPE

1. The present study can be extended by considering nonlinear time history analysis for more realistic dynamic response evaluation.
2. Soil–structure interaction may be included to understand the effect of pile flexibility and seabed conditions on offshore platform behaviour.
3. Fatigue analysis should be carried out because offshore platforms are subjected to repeated wave and wind loading during their service life.
4. Corrosion effects may be included to evaluate long-term degradation of tubular steel members in marine environments.
5. Additional bracing configurations such as X-bracing, K-bracing, V-bracing and inverted V-bracing may be compared with single, double and knee bracing systems.
6. Hydrodynamic analysis using Morison's equation and different wave theories may be incorporated for more accurate wave force estimation.
7. Optimization techniques can be applied to minimize structural weight while maintaining safety and serviceability.
8. Experimental validation using scaled physical models or shake table testing may be performed to verify numerical results.

11. REFERENCES

1. Neeta Chavhan et al. (2019). Analysis of Offshore Structure Having Different Bracing Pattern Using SAP2000.
2. Gande Sandhya (2018). Analysis of Offshore Jacket Structure.
3. Yousuf Ahmed and Kumar (2019). Seismic Behaviour of Offshore Steel Jacket Platform Braced in Horizontal and Vertical Planes.
4. Supriya and Abhilash (2024). Evaluating Bracing Configurations in Offshore Structures under Multi-Load Conditions.
5. Shehata E. and Abdel Raheem (2013). Nonlinear Response of Fixed Jacket Offshore Platform under Structural and Wave Loads.
6. Juswan et al. (2020). The Influence of Effective Length and Reduction Factor to Buckling on Jacket Brace.
7. Faseela A. and Jayalekshmi (2015). In-Place Strength Evaluation of Jacket Platforms and Optimization of Bracing Configurations.
8. Md Samdani Azad et al. (2018). Effects of Redundancy in Bracing Systems on the Fragility Curve Development of Steel Jacket Offshore Platform.
9. Deepak Khandelwal (2018). Design/Analysis Procedures for Fixed Offshore Platform Jacket Structures.

10. Walid Kamali et al. (2022). Analysis and Design of a Jacket Offshore Structure in the Lebanese Coast.
11. Bipasha Das (2017). Model Development and Load Analysis of Offshore Jacket Structure using SAP2000.
12. Ashwini Chalke et al. (2020). Equivalent Static Analysis of Offshore Structure.
13. Qian Wang (2021). Structural Optimization in Civil Engineering: A Literature Review.