# EQUIVALENT STATIC ANALYSIS OF OFFSHORE STRUCTURE

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*Abstract :* A linear static analysis of an offshore platform under wave loading is presented the structures using the finite element method. The wave and current forces acting on the structure are computed by using stoke 5th order equation, which decomposes the total force into an inertia component and a drag component. The structure is nearly 136 ft deep and three different configurations of models with lateral bracing are use for offshore structure. The equivalent static load analysis done in this study, using the SAP2000 V20 software subjected to various load such as wave load , dead load, live load, wind load have been used to calculate the Natural time period , Mode shape and Displacement due to wave loading.

***Keywords -*** Offshore Structure, Nonlinear Analysis, Finite Element Analysis, Wave Structure Interaction, Wave Loading, Wind Loading.

## I. INTRODUCTION

Offshore platform are used for oil exploration and production, navigation, ship loading and unloading, and to support bridges and causeways. Analysis and design of such structures are challenging as these structures are subjected to extreme environment conditions. Offshore platforms are generally constructed using steel and concrete. It consists of pile as a foundation, jacket as a supporting structure and a top side structure to accommodate the equipment. Offshore structures are among the tallest and heaviest structure on earth. Depending upon different types of materials used and the height of sub structure there are classified into three categories i.e. Gravity based, Jacket platform and Tension Leg Platform. In gravity based structure, a concrete caisson is bought to site and placed on sea bed then after it is filled by sand or gravel (Sadeghi & Sadeghi, 2007) .This structure is most efficient for shallow depth up to 50-60m, as depth increases the construction of this kind of structure become uneconomical because of huge weight. For deeper construction i.e. up to 100-140m Jacket Platforms are most cost efficient. This Jacket Platform is made up of Legs and bracing system. If the site is deeper generally greater than 500m, Tension Leg Platform can be used. In Tension Leg Platform the pontoon kind of structure is supported by cables, these cables are always remains in tension that's why it is called Tension Leg Platform. Offshore structure is subjected to extreme environment condition due to wind and wave loadings. Analysis and design of these kinds of structure are challenging. 25 to 30 percent of total project cost is involved in the construction (Martens, 2014).Hence little bit saving in construction will led to more economical design. Hence optimization plays significant role in design.

## II. PROJECT UNDERTAKEN

For offshore structure, four legged jacket platform is considered. This structure consists of four legs, four piles and topside platform. The jacket is supported on pile. The structure is nearly 136 ft deep. This structure is made up of steel. Optimization has been performed using 5th order stoke laws technique.

Offshore structure requires special attention for economic design in analysis of equivalent static method for finding out displacement, natural time period and modal mass participation. On that basis offshore structure is analyzed using SAP2000 V20 software to understand mode behavior of structure for safe design. In report three different configurations are prepaid which have different width and angle but other geometry as height , thickness of jacket platform and other properties of steel having same data for more accuracy of results.

## III. MODELING AND ANALYSIS

For the current study, different type of offshore structure of 110 ft. and the structure located in sea is considered. Equivalent static analysis of these three different types of offshore structure was done for wind loading and wave loading and also different angle various bracing is use. Equivalent static analysis performance offshore structure was studied and comparison of various parameters likes natural time period, joint displacement and modal mass participation. Equivalent static analysis was done as per APIWSD 2000 code and check of all members design was taken.

The studied platform is a fixed Jacket Type platform currently installed in the Suez gulf, Red sea, 1988. The offshore structure is a four legs jacket platform, consists of a steel tubular space frame. There are diagonal brace members in both vertical and horizontal planes in the units to enhance the structural stiffness.

### *3.1 Simulation*

The equivalent static analysis consists of the several stages listed below.

1. Equivalent static analysis of offshore structure of both structures is done as per APIWSD 2000 code and verified all structural members' analysis.
2. Equivalent static analysis of controlled displacement type is done as per guidelines of API WSD Council (API). Liner

load case for dead load and live load was defined from linear static load case. New static load cases are defined as wave and wind for x and y direction.

3. Equivalent static analysis is done. The analysis result are studied for the structural condition
4. From analysis results modal mass participation, natural time period and displacement is determined.
5. Finally from equivalent static analysis results, natural time period and mode shape is plotted. The plotted graph shows value of time period and mode shape.

### 3.2. STRUCTURE DETAILS AND DESIGN LOADING

*1. Steel material*

AISC code use for selection of steel section Grade of steel section is A36

*2. Design Wave Loading*

Use code for wave loading API WSD 2000

| | |
|---|---|
| Mud line from datum | = 110 ft. |
| High tide from datum | = 36 ft. |
| Sea water density | = 0.064 |
| Wave height | = 35.2 ft. |
| Wave period | = 8 sec |
| Apparent wave period | = 8 sec |
| Strom water depth | = 132 ft. |

Idealization of above problem statement is modeled in finite element analysis tool SAP 2000 v20. Following models are prepared for comparative analysis of offshore steel structure.

*3. Design Wind Loading*

Use code for wind loading API4F 2013 Wind Velocity = 93 ft. /sec
SS Multiplier = 1
Shielding Coefficient = 0.85
Wind Direction Angle = 0

*Wind speed and force relationship*

The wind drag force on an object should be calculated equation in 3.2

$F=0.5\rho CsAU^2$ ………3.2

F = wind force,
$\rho$ = mass density of air, (slugs/$ft^3$, 0.0023668 slugs/$ft^3$ for standard temperature and pressure),
u = wind speed (ft/sec) Cs = shape coefficient,
A = area of object ($ft^2$)

***Table 3.2: Wave loading parameter values***

| Definitions | Water depth (MSL) ft | LAT (MSL) ft | HAT MSL ft | Tide (ft) | Hmax (ft) | Tp (sec) |
|---|---|---|---|---|---|---|
| -year return period wave for operating conditions | 110' | -6' | 6' | 3' | 17' | 6.5 |
| year return period wave for safety conditions | | | | 5' | 26' | 8 |

### 3.3 FIXED JACKET PLATFORM OFFSHORE MODELS

| | |
|---|---|
| Model No. 1 | offshore platform with double bracing 90 degree |
| Model No. 2 | offshore platform with knee bracing 90 degree |
| Model No. 3 | offshore platform with single bracing 90 degree |
| Model No. 4 | offshore platform with double bracing 60 degree |
| Model No. 5 | offshore platform with knee bracing 60 degree |
| Model No. 6 | offshore platform with single bracing 60 degree |
| Model No. 7 | offshore platform with double bracing 40 degree |
| Model No. 8 | offshore platform with knee bracing 40 degree |
| Model No. 9 | offshore platform with single bracing 40 degree |

***Table 3.3: Offshore Fixed Platform Model***

**A. Offshore Platform With Different Bracing 90 Degree Models**

Figure. 3.3.1 to 3.3.3 shows offshore platform structure with 90 degree angle providing double, knee, single bracing. Fixed jacket platform is best suited for low water depth (around 132 feet). This type of structure is directly in contact with sea bed so the lateral stability of this structure is very high. This type of structure is generally made up of steel. The structure consists of four legs on which top side platform is constructed. The top and base (720"x720") dimension of structure is same in 90 degree angle.

Fig. 3.3.1: Offshore platform with double bracing 90 degree

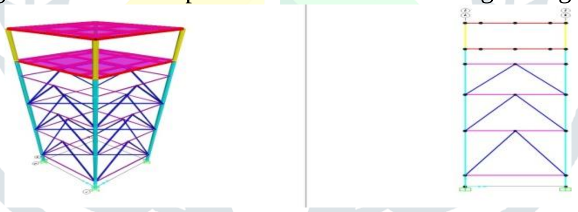


Fig. 3.3.2: Offshore platform with knee bracing 90 degree

Fig. 3.3.3: Offshore platform with single bracing 90 degree

**B. Offshore Platform with Different Bracing 60 Degree Models**

Figure.3.3.4 to 3.3.6 top dimension of platform is (590"x590") and base dimension is (720"x720") and model angle is 60 degree with double bracing. Offshore platform structure with 60 degree angle providing double, knee and single bracing. This type of structure is directly in contact with sea bed so the lateral stability of this structure is very high. This type of structure is generally made up of steel.

Fig. 3.3.4: Offshore platform with double bracing 60 degree

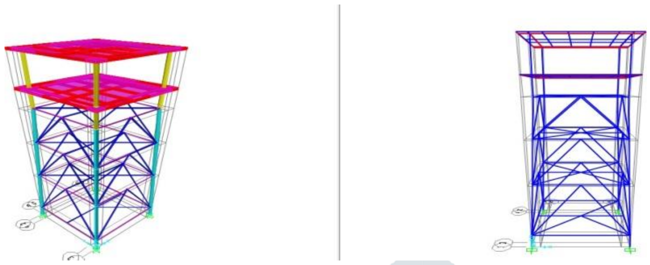


Fig. 3.3.5: Offshore platform with knee bracing 60 degree

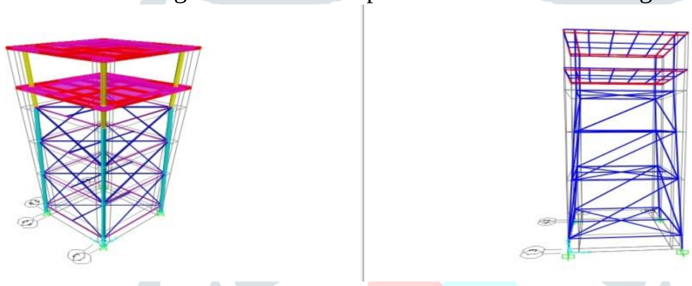


Fig. 3.3.6: Offshore platform with single bracing 60 degree

**C. Offshore Platform with Different Bracing 40 Degree Models**

Figure.3.3.7, 3.3.8 and 3.3.9 shows offshore platform structure with 40 degree angle providing double, knee and single bracing. This type of structure is directly in contact with sea bed so the lateral stability of this structure is very high. This type of structure is generally made up of steel. The top dimension of platform is (460"x460") and base dimension is (720"x720") and angle is 40 degree with different bracing.

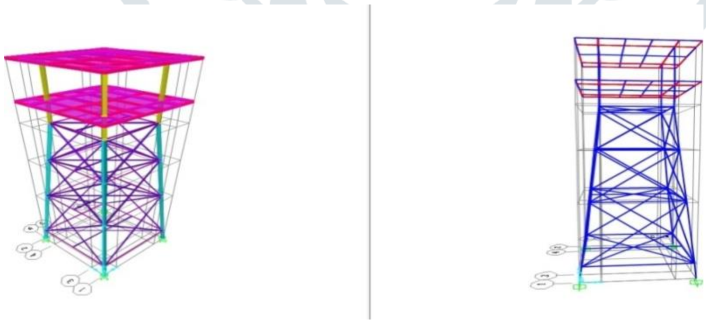


Fig. 3.3.7: Offshore platform with double bracing 40 degree

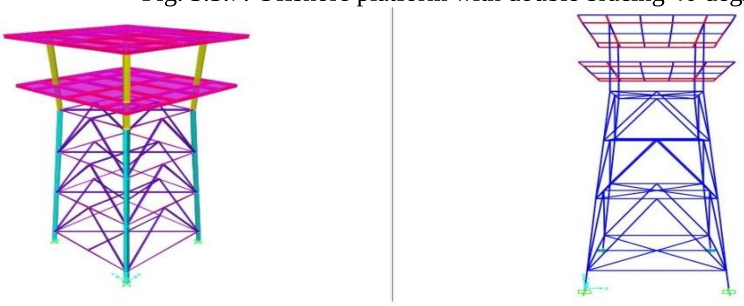


Fig. 3.3.8: Offshore platform with knee bracing 40 degree

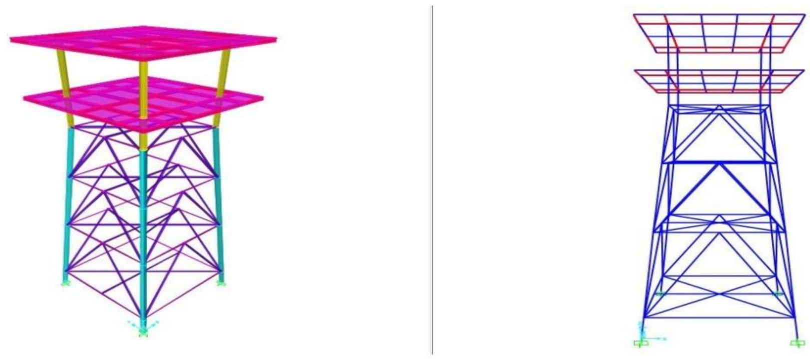


Fig. 3.3.9: Offshore platform with single bracing 40degree

## IV. RESULT AND DISCUSSION

Results of the study are presented and discussed with reference to the objective and scope of the study. The results are mainly categorized in two main parts various angle and different type of bracing. The angle requirement includes modal mass participation and displacement. The majority of the world's platforms have been designed according to the different editions of recommended practice by "The American Petroleum Institute", which until 1993 has been in working stress design format. American Petroleum Institute LRFD, 1993 provisions provide characterization of environmental load and design requirement for fixed offshore platform for use in analysis. The consideration of environmental loads are consist, wind, and wave.

### 4.1. Offshore Platform 90 Degree Mode

Table 4.1.1: Joint displacement due to wave loading double bracing 90 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 170 | Wave | Lin MSStat | Max | 0.048151 |

Table 4.1.2: Joint displacement due to wave loading knee bracing 90 degree inclined leg

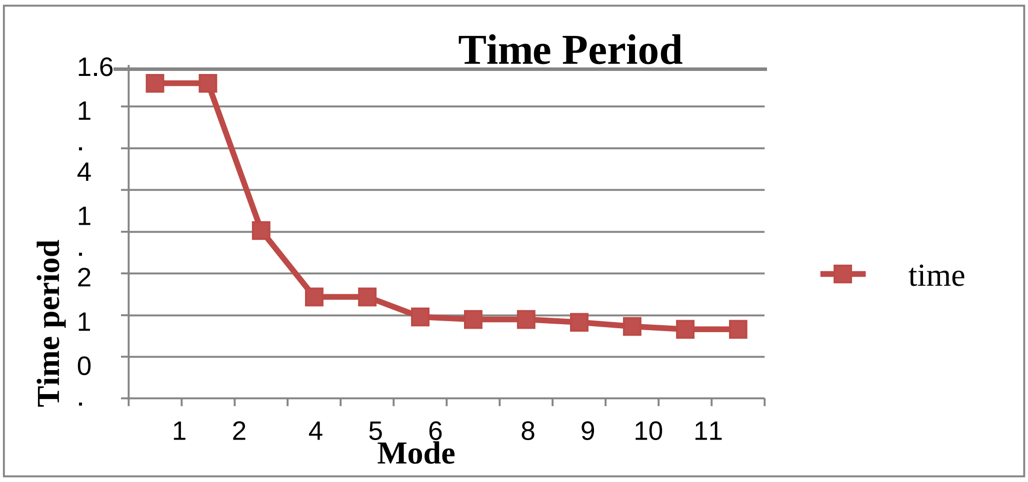
| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacemen t (inch.) |
| 8 | Wave | LinMSSta t | Max | 0.049315 |

Table 4.1.3: Joint displacement due to wave loading single bracing 90 degree inclined leg

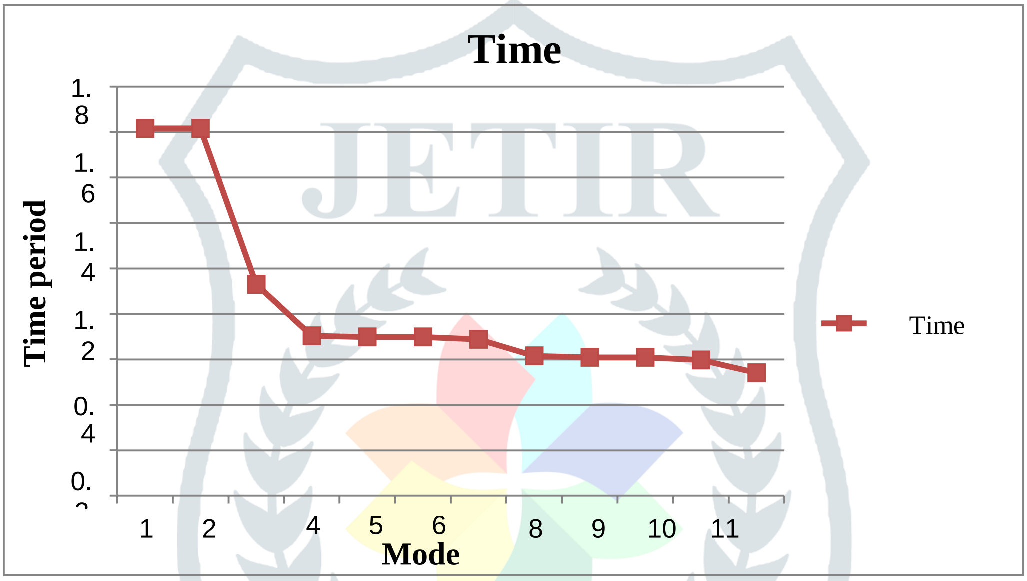
| Joint displacements | | | | |
|---|---|---|---|---|
| Join t | Output Case | Case Type | Step Type | Displacement (Inch.) |
| 114 | Wave | LinMSSt at | Max | 0.009045 |

Joint displacement for 90 degree offshore structure are analyzed in inch dimension, where single bracing joint displacement value is 0.009045 which is very less as compare to other two bracing, it is conclude that single bracing with 90 degree offshore structure, have effect of angle of angle of structure to perform better, in knee and double bracing joint displacement is 0.049315 and 0.04815 respectively are exactly near to each other

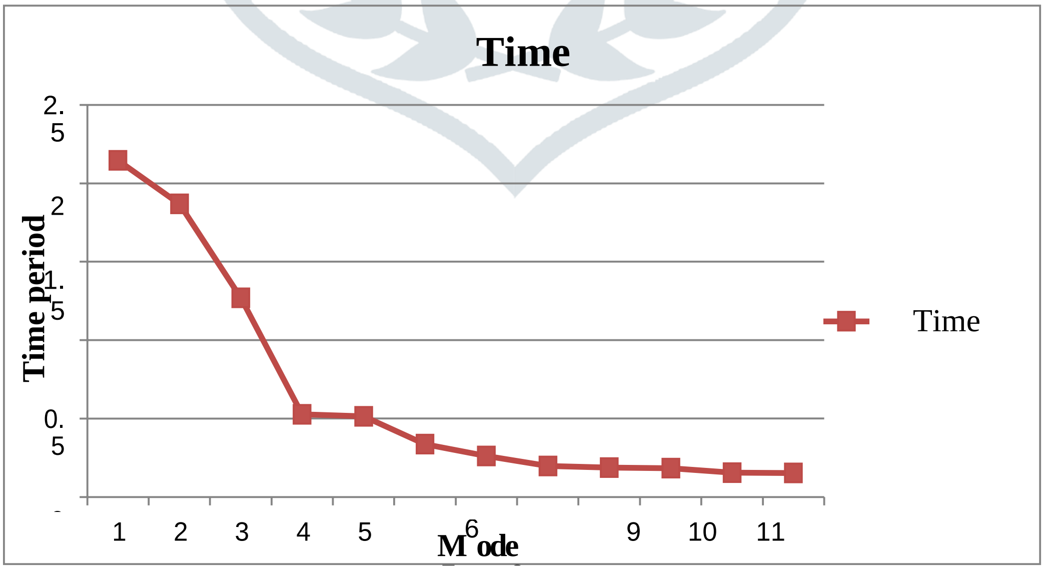
*Graph 4.1.1: Mode shape vs. natural time periods double bracing 90 degree inclined leg*




*Graph 4.1.2: Mode shape vs. natural time period knee bracing 90 degree inclined leg*




*Graph 4.1.3:Mode shape vs. natural time period single bracing 90 degree inclined leg*




From Graph 4.1.1 to 4.1.3, offshore platform with double bracing and knee bracing with 90 degree model, shows natural time period of 1.51 sec and 1.61 sec respectively, which is nearly close spaced value, while single bracing shows natural time period of 2.14 sec for same model, hence double and knee bracing perform quite well as compare to single bracing for natural time period.

**4.2. Offshore Platform 60 Degree Mode**

Table 4.2.1 Joint displacement due to wave loading double bracing 60 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 52 | Wave | LinMSStat | Max | 0.023492 |

Table 4.2.2: Joint displacement due to wave loading knee bracing 60 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 53 | Wave | LinMSStat | Max | 0.011496 |

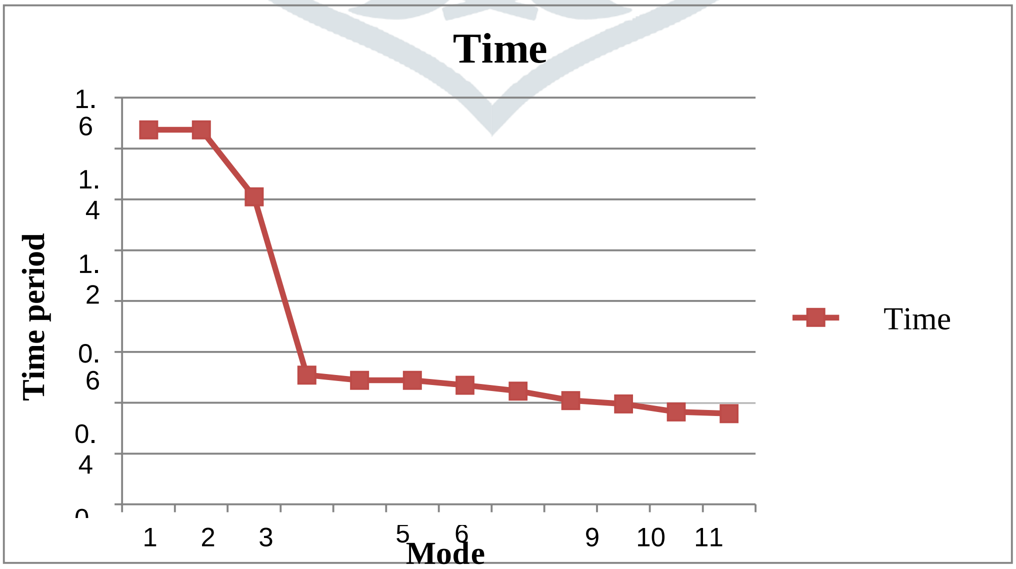
Table 4.2.3: Joint displacement due to wave loading single bracing 60 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 53 | Wave | LinMSStat | Max | 0.010466 |

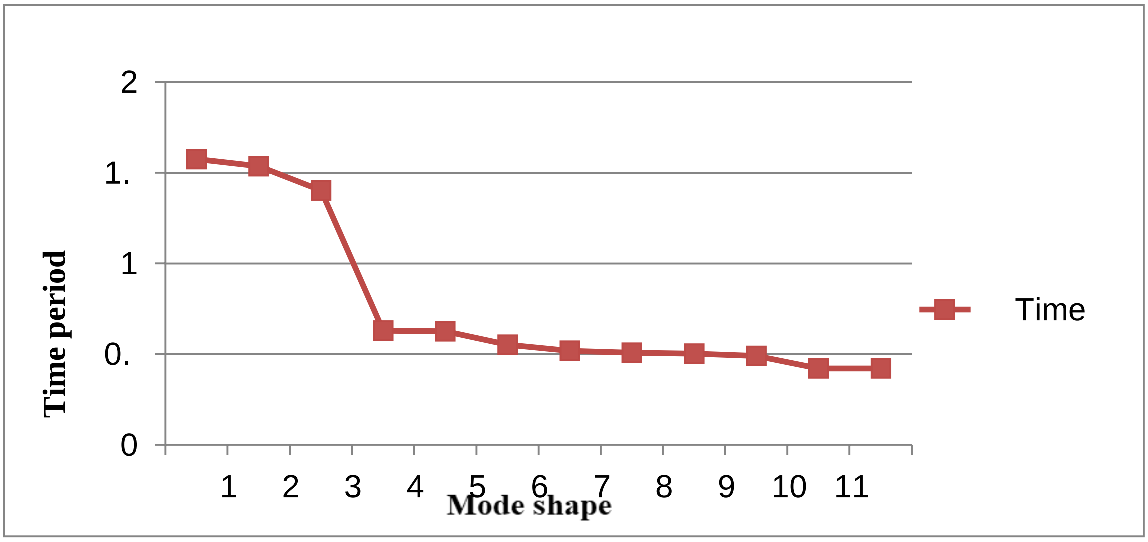
Joint displacement for 60 degree structure, single bracing and knee bracing results are close to each other that is 0.010466 and 0.011496 respectively. Where double bracing having joint displacement of 0.02347 which is greater than the knee and single bracing is near, if we compare those three results single bracing, for 60 degree give better results than other two bracing.

From the graph 4.2.1 to 4.2.2 it has been observed that the time period reduced with respect to number of modes shape

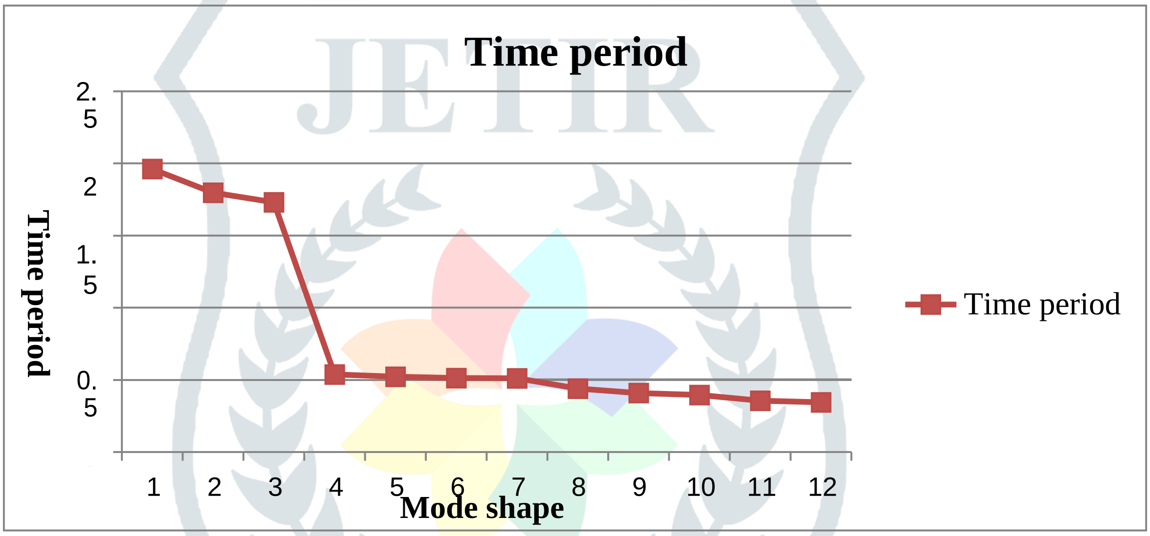
*Graph 4.2.1:Mode shape vs. natural time period double bracing 60 degree inclined leg*



*Graph 4.2.2: Mode shape vs. natural time period double bracing 60 degree inclined leg*




*Graph 4.2.3:Mode shape vs. natural time period double bracing 60 degree inclined leg model*




From graph 4.2.1 to 4.2.3 of offshore platform with double bracing and knee bracing with 60 degree model shows natural time period of 1.47sec and 1.57 sec respectively, which is closely spaced and quite similar to 90 degree model results, while single bracing indicate

Value of 1.95 sec, hence for 60 degree model double and knee bracing perform better as compare to single bracing.

**4.3 Offshore Platform 40 Degree Inclined Leg**

From the table 4.3.1, 4.3.2 and 4.3.3 it has been observed that the time period reduced with respect to number of modes shape.

Table 4.3.1: Joint displacement due to wave loading double bracing 40 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 56 | Wave | LinMSSt at | Max | 0.010414 |

Table 4.3.2: Joint displacement due to wave loading knee bracing 40 degree inclined leg

| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 61 | Wave | LinMSStat | Max | 0.008452 |

Table 4.3.3: Joint displacement due to wave loading single bracing 40 degree inclined leg

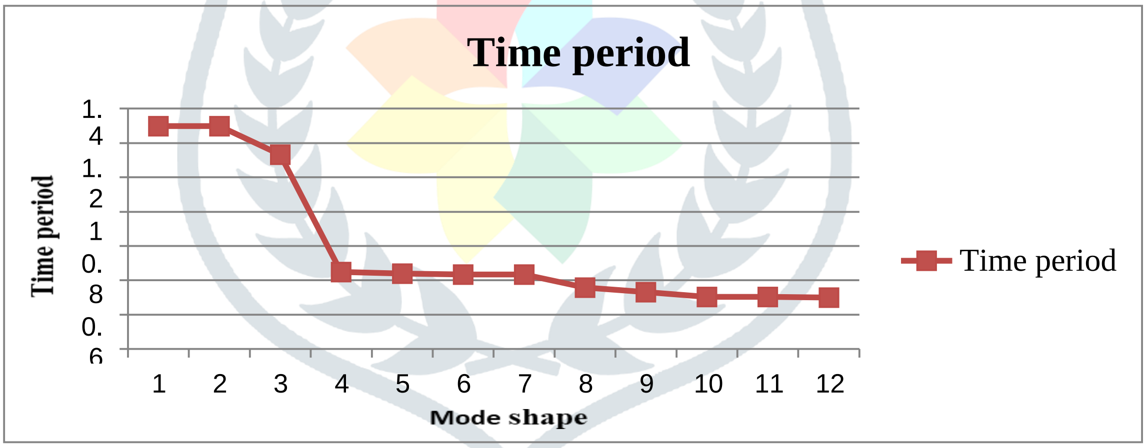
| Joint displacements | | | | |
|---|---|---|---|---|
| Joint | Output Case | Case Type | Step Type | Displacement (inch.) |
| 56 | Wave | LinMSStat | Max | 0.010341 |

Joint displacement for 40 degree inclined leg offshore structure, knee bracing performance are good enough when compare to other two bracing, where knee bracing give joint displacement of 0.00842 inch which is much more less than value of double bracing 0.010414 and single bracing 0.010341 , where double and knee bracing joint

Displacement value are close each other. Here, it can conclude that in all cases of bracing with different angle, angle of structure having great impact on joint displacement.

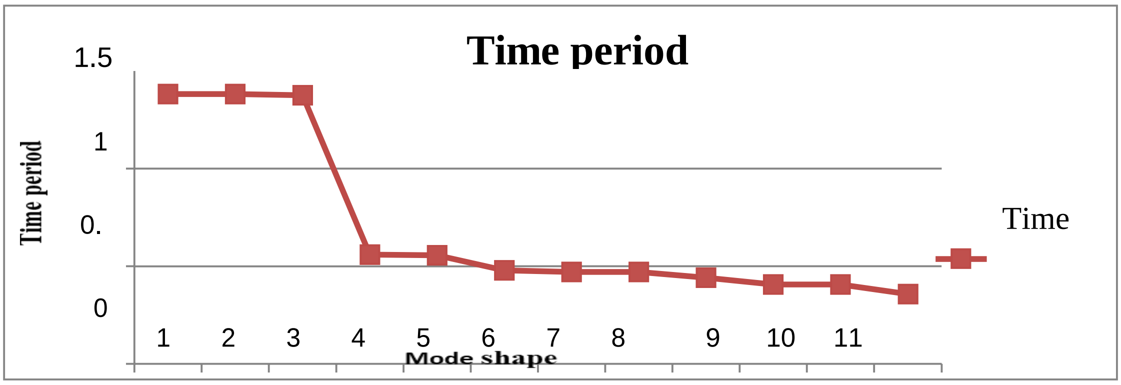
From the graph 4.3.1 to 4.3.3 it has been observed that the time period reduced with respect to number of modes shape.

*Graph 4.3.1:Mode shape vs. natural time period double bracing 40 degree inclined leg*

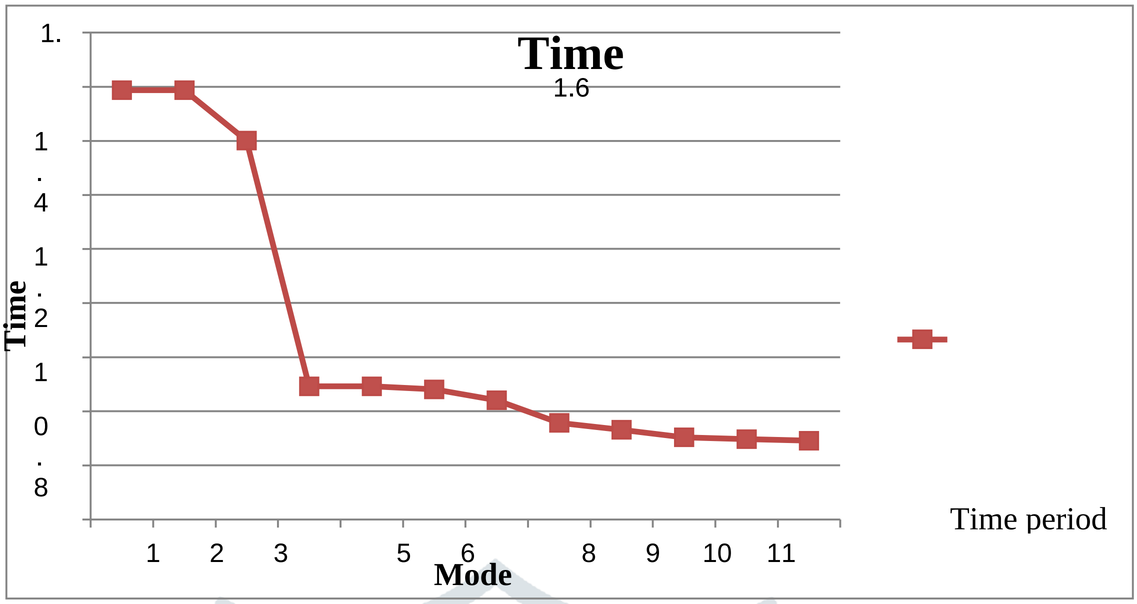



Graph 8.7: Mode shape vs. natural time period

*Graph 4.3.2:Mode shape vs. natural time period knee bracing 40 degree model inclined leg*



*Graph 4.3.3:Mode shape vs. natural time period single bracing 40 degree inclined leg*




From Graph 4.3.1 to 4.3.3, offshore platform with double bracing and knee bracing with 40 degree model, shows natural time period of 1.29 sec and 1.38 sec respectively, which is nearly close spaced value, while single bracing shows natural time period of 1.58 sec for same model, hence double and knee bracing perform quite well as compare to single bracing for natural time period.

## V. CONCLUSIONS

1. **O**ffshore platform with inclined leg angle 90 degree. The natural time period of bracing are closely spaced, while single bracing time period increased 1.4 times as compare to double and knee bracing.
2. model perform in any inclined leg angle i.e. 90, 60 or 40 degree with different bracing , but results indicates that variation of natural time period increase or decrease is same in all leg angles and bracing.
3. Comparing double bracing with knee bracing, the knee bracing time period increase 1.06 times as compare double bracing shows quite good performance in natural time periods.
4. Offshore platform with 90 degree inclined leg angle in modal modal mass participation, in single and knee bracing increase 3 to 5 % as compare double bracing.
5. Offshore platform with 90 degree inclined leg angle in joint displacement, in knee and double bracing increase 2 to 5 % as compare double bracing.
6. offshore platform modal mass participation for 90 degree,60 degree and 40 degree model shows satisfactory results for all three type of bracing which follows criteria of API WSD 2000 mentions structure which having above 90 percentage of mass participation will resistant to failure of structure

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