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An Analytical Study on Behaviour of Fixed Offshore Jacket Structure

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Abstract - *Fixed offshore jacket structures have been used extensively in oil and gas exploration and production industry. These structures may be subjected to large lateral loads, especially wave and seismic loads and they may be provided at locations of varying water depths. The present study evaluates the behaviour of fixed offshore jacket structures for different water depth and wave heights. A typical 4-legged battered jacket structure has been modeled using STAAD Pro. Under combined vertical and lateral environmental loading. Deck load, wind forces and current velocities are considered to remain constant in this study. The water depth (60m, 90m and 120m) and wave height (5m, 10m and 15m) have been varied. The base of the jacket structure is considered fixed. The results of maximum lateral and vertical deflection, governing support reactions and maximum member forces (axial force, shear force and bending moment) are compared and discussed to understand the effect of water depth and wave heights on the behaviour of offshore jacket structure. The study results would be useful for optimizing the design of jacket structures.*

Key Words: jacket structure, wave load, water depth, wave height, structural behaviour

1. INTRODUCTION

Fixed offshore jacket structures, usually welded tubular space frame structures, are required in oil and gas sector. They are provided in different water depths depending on location of oil and gas resources. Earlier studies have focused on understanding the behaviour of offshore jacket structures. These studies include effect of different types of loading, effect of geometrical configuration, strength assessment, inelastic behaviour, soil-structure interaction and failure modes [1-8]. Nayak and Pandian (2018) [1] studied the effect of environmental loads such as wind, current and wave loading on behaviour of fixed base jacket structure using SACS software. It has been noted that diagonal wave load is more critical for design. Uplift forces have been observed to reduce with increase in steepness of leg and a leg batter of 1:9 has been recommended in the study. Sandhya (2018) [3] studied jacket structure using SACS software. It has been recommended that the methodology of analysis proposed in this study using the SACS software is suitable for jacket structure and can accurately predict the forces in different members subjected to combination of vertical and environmental loading. Another study by Henry (2017) [4] suggested that the design of jacket structure is governed mainly by wave loads. Ishwarya et al. (2016) [5] studied the fixed jacket structure with different bracing patterns, viz., x-bracing, x+chevron bracing, chevron bracing and v-bracing; considering soil-structure interaction. It was concluded that the type of bracing does not significantly affect the seismic design of jacket structure, as the failure of first member was observed to occur at comparable base shear values. Potty and Sohaimi (2013) [6] studied the offshore platform reliability and observed that the structure with 8-legs yielded at higher ultimate load as compared to 3-legged and 4-legged structures. The study also noted that x-bracing provides better rigidity as compared to other bracing patterns.

Raheem et al. (2012) [7] performed the nonlinear analysis of offshore structure under the effect of wave loading with up to 100 year return period. It has been suggested that reducing dynamic stress amplitude of an offshore structure by 15% would double the life of the structure. The displacement response increases non-linearly with structure height, with significant curvature at top of the structure. It has been recommended that lower maximum deck acceleration was desirable for better functioning of vessels and equipment on offshore platform, while, small deck-to-top of shaft displacement was required for the risers and caissons. Asgarian et al. (2018) [8] studied the failure modes for offshore structures and concluded that whenever the jacket structure is significantly stronger than foundation, the failure mode is usually by plastic hinge formation in piles. Increase in the pile moment of inertia was noted to cause buckling of bracing connected to the pile followed by failure of pile. Reduction in pile length to meet only codal minimum safety factor requirement, increases the risk of pull out failure of piles. It has been suggested that the pile sizing has significant effect on the failure mode for offshore structure.

A review of above literature provides insight on existing state-of-the art of the studies on offshore jacket structure. However, limited studies focus on behaviour of jacket structure due to the effect of change in water depth and wave height. Hence, the objectives of the present study is to understand the effect of different water depths (60m, 90m and 120m) and wave heights (5m, 10m and 15m) on the support reactions, jacket structure deflection and member forces. The details of the structure considered, STAAD analysis model and results are discussed in the following sections.

2. Details of STAAD Pro. Analysis of Jacket Structure

In the present work using STAAD Pro., in-place static analysis on a typical X-braced, square, 4-legged battered jacket structure is done. Details of section dimensions of various members are given in Table 1. The jacket is having a batter of 1:8 and the supports are modelled as fixed at sea bed level. It is subjected to a combination of vertical and lateral environmental loads. Vertical loads consist of self-weight, deck and conductor loads. The environmental loadings viz. wind, wave and current forces are considered in orthogonal and diagonal directions viz. 0^0, 45^0 and 90^0, with respect to jacket structure. Wave and current forces on jacket structure are calculated using Morrison's equation considering Stokes 5th order wave theory. Constant values of deck load, wind force and current velocity is considered in this study. Water depth (60m, 90m and 120m) and wave height (5m, 10m and 15m) are the variables considered in this study. Figure 1 shows the 3-dimensional STAAD model of the jacket structure with deck loading, Figure 2 presents the application of wave and current load, and Figure 3 presents the application of wind load in STAAD model.

Table - 1: Dimensions of member's section

MEMBER	OUTER DIAMETER (m)	THICKNESS (mm)
Leg	2	60
Beam	1.1	30
Braces	0.9	20

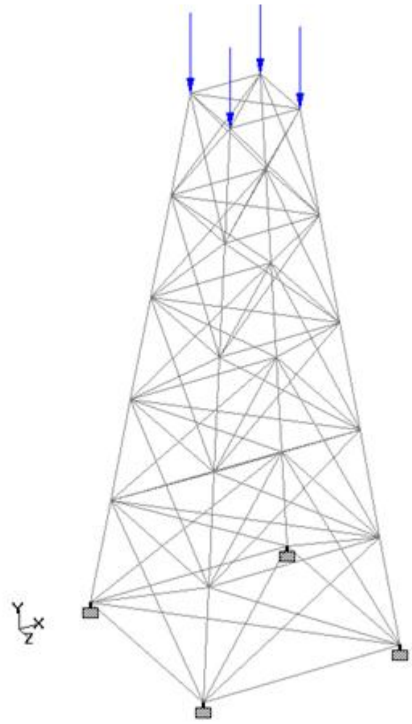

Figure - 1: 3-Dimensional STAAD model of Jacket structure with deck load

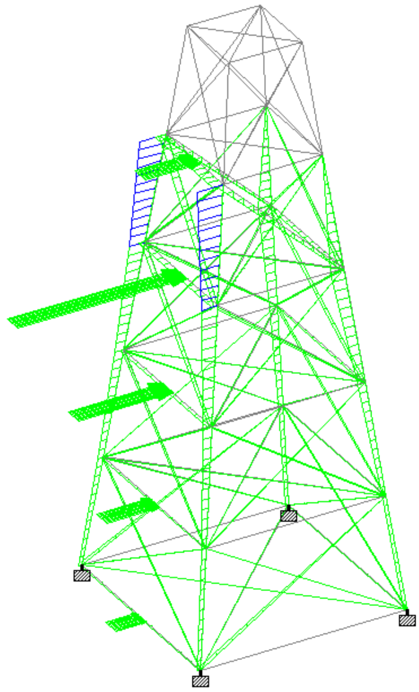

Figure - 2: Application of wave & current load on Jacket structure and conductors pipes

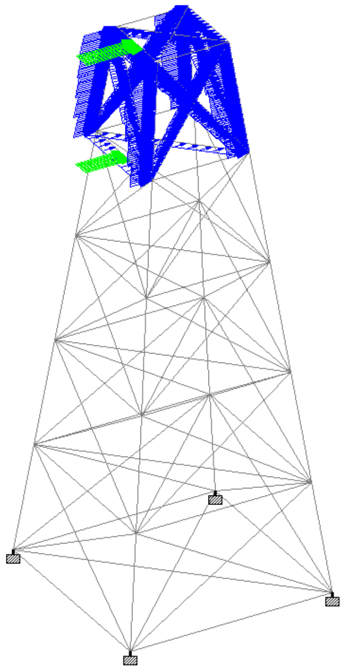

Figure - 3: Application of wind load on Jacket structure and conductors pipes

3. Results and Discussion

The maximum lateral and vertical deflection, support reactions and member forces for all the cases studied viz., water depths of 60m, 90m and 120m and wave heights of 5m, 10m and 15m are plotted in charts below. Charts 1 & 2 present the comparison of maximum lateral and vertical deflection, respectively. It can be seen that lateral deflection of jacket structure increases almost linearly with increase in water depth as well as wave height. The effect of change in wave height is more predominant for lateral deflection at top of the structure. The vertical deflection increases linearly with increase in water depth, while no visible impact of change in wave height on vertical deflection is noted. Charts 3 & 4 show the maximum and minimum vertical support reactions, respectively. Minimum reaction is observed for load combination without deck load. As expected, the maximum and minimum vertical support reaction increases linearly, with increase in water depth. The impact of increase in wave height on the vertical support reaction is not significant. It may be seen that there is no tension observed in support. This may be due to higher weight of structure owing to more height of jacket structure (depends on water depth and deck position). Further, the study objectives are not focused on optimization of member sizes which would affect the weight of the structure as well as lateral loads due to wind and wave loads. However, in design for real life projects, optimization of member sizes shall be carried out to yield best design option for the given project. Charts 5 & 6 present maximum horizontal reaction and support moment. It can be seen that similar to vertical reactions, horizontal reaction and support moment also increase linearly with water depth. The effect of wave height on support moment is higher than on horizontal reaction.

Charts 7 & 8 show the variation of maximum axial force in legs and beams of jacket structure. The axial force in legs, follow the trend for maximum vertical support reactions and increases linearly with increase in water depth, with insignificant variation with increase in wave height. The axial force in beams appears to be independent of the water depth and wave height. This may be attributed to predominant contribution of vertical and plan bracing in distributing the lateral loads.

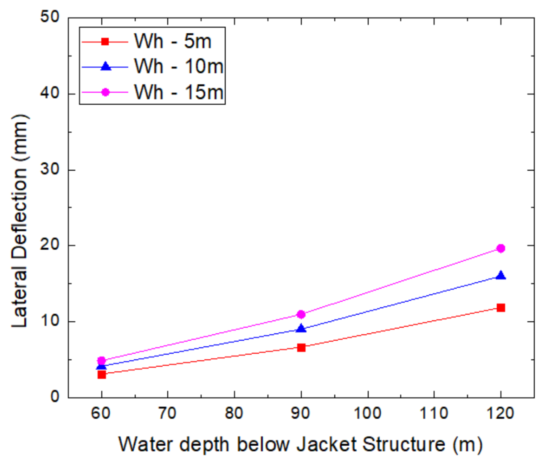

Chart - 1: Maximum lateral deflection for jacket structure

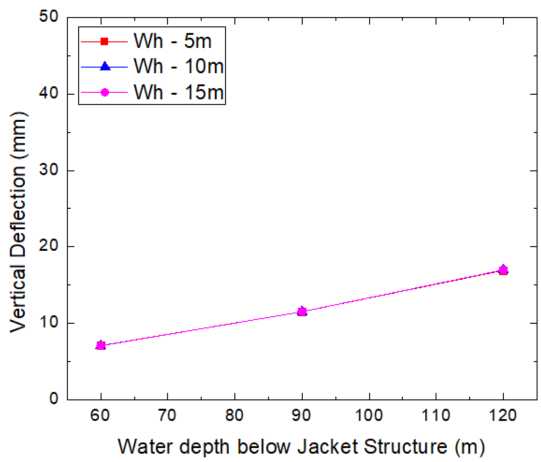

Chart - 2: Maximum vertical deflection for jacket structure

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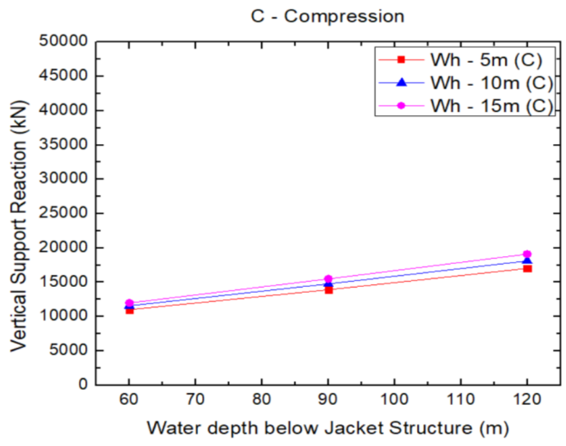

Chart - 3: Maximum vertical support reaction for Jacket structure

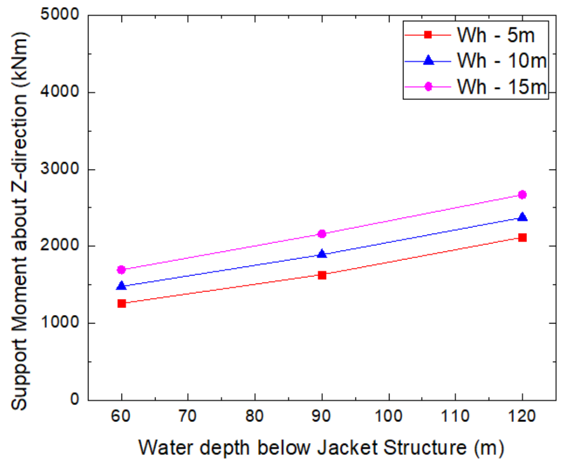

Chart - 6: Maximum support moment for jacket structure

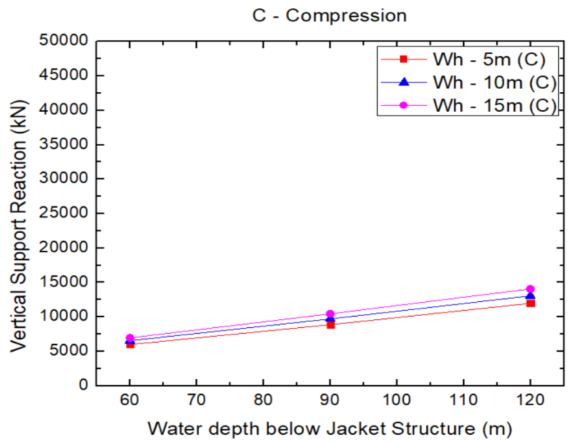

Chart - 4: Minimum vertical support reaction for standalone jacket structure without deck load

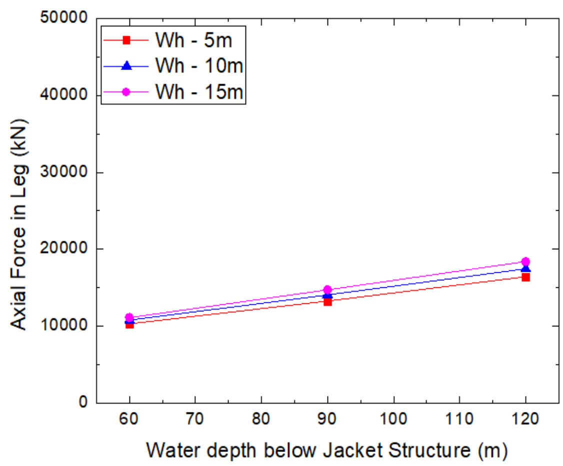

Chart - 7: Maximum axial force in legs of jacket structure

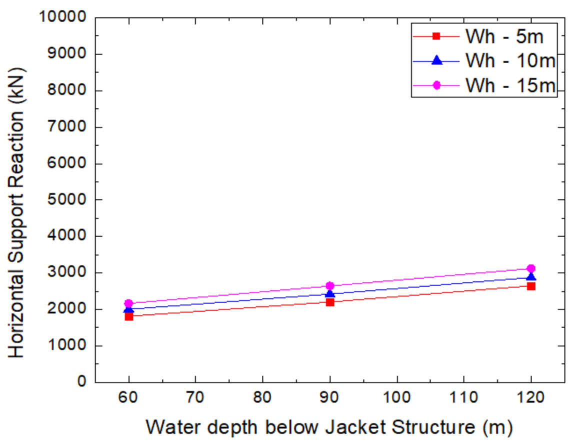

Chart - 5: Maximum horizontal support reaction for jacket structure

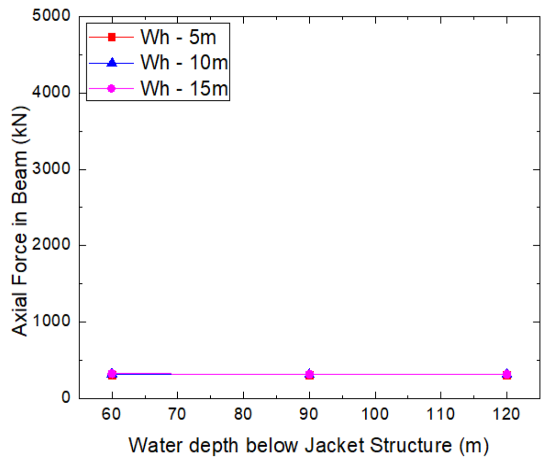

Chart - 8: Maximum axial force in beams of jacket structure

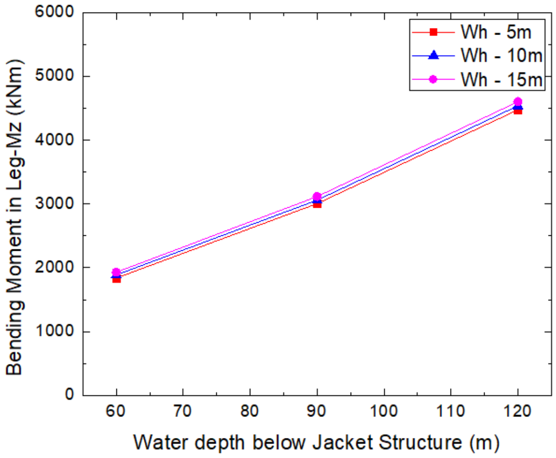

Chart - 9: Maximum bending moment in legs of jacket structure

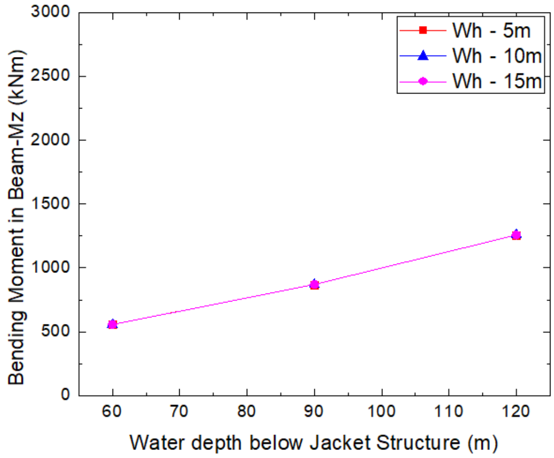

Chart - 10: Maximum major axis bending moment in beams of jacket structure

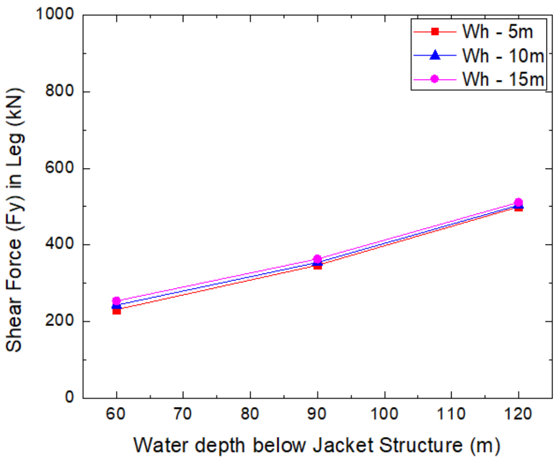

Chart - 11: Maximum shear force in legs of jacket

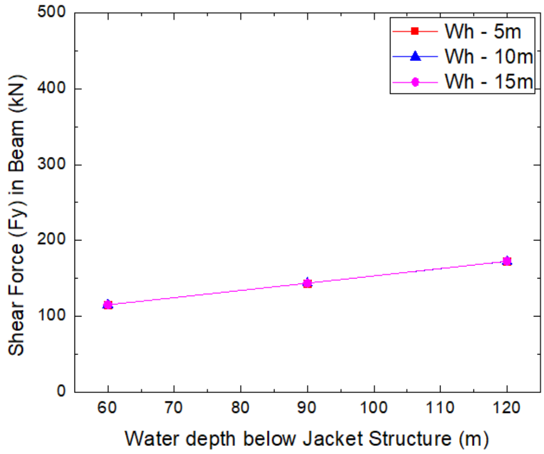

Chart - 12: Maximum vertical shear force in beams of jacket structure

The variation of maximum bending moment and shear force in legs and beams is shown in Charts 9 to 12. The bending moment and shear force in legs and beams increases significantly (about 2.5 times) with increase in water depth from 60m to120m, and the variation is mostly linear. However wave height does not appear to have visible impact on the bending moment and shear force. This is due to the fact that the difference in governing load (wave load) for wave heights of 5m, 10m and 15m is not very significant considering the large height of structure below water. The effect of water depth and wave height variation on the minor axis bending moment and shear force for beams are in shown in Charts 13 & 14. It can be observed that interestingly, the water depth has no significant effect on the shear force and bending moment of beam in minor axis. However, with increase in wave height, these forces are almost doubled. This can be explained by the fact that the wave load acting on the beam cause local lateral shear force and lateral bending of the beam, and increase in wave height increase these local beam forces. The beams at the top of jacket structure are expected to be more affected by increase in wave height as compared to beams below water surface.

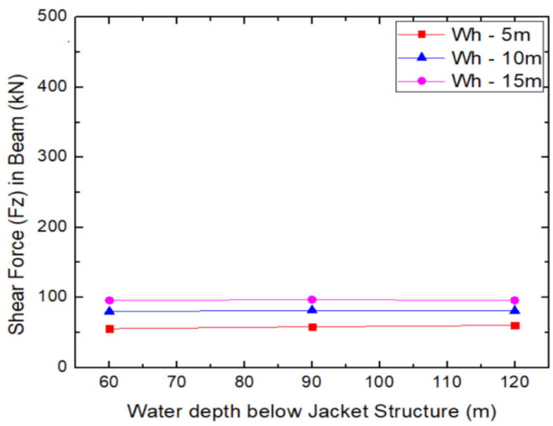

Chart - 13: Maximum horizontal shear force in beams of jacket structure

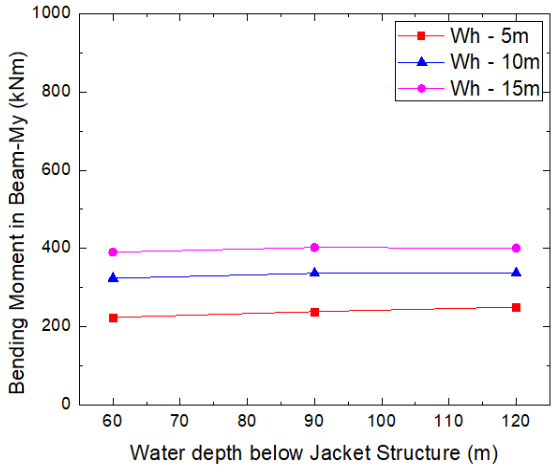

Chart - 14: Maximum minor axis bending moment in beams of jacket structure

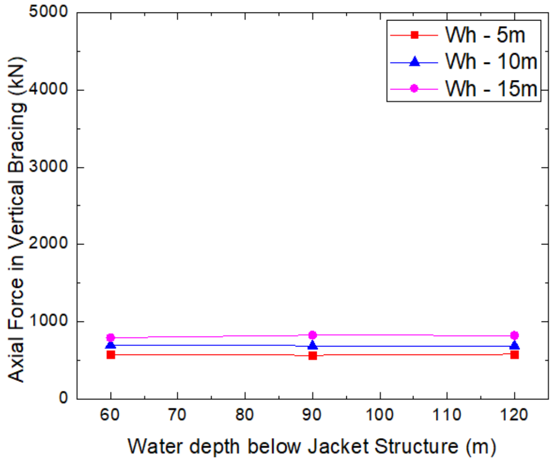

Chart - 15: Maximum axial force in vertical bracings of jacket structure

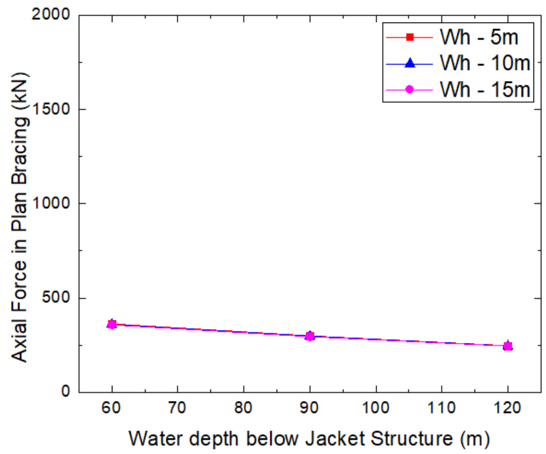

Chart - 16: Maximum axial force in plan bracings of jacket structure

The forces in the vertical and plan bracing, is presented in Charts 15 to 20. The axial forces in the vertical bracing slightly increases with increase in wave height, however there is no significant effect of water depth. This may be due to distribution of force to more number of vertical bracings and plan bracings as height of structure increases. For plan bracing, the maximum axial force slightly reduces with increase in water depth. Also the effect of wave height on axial force in plan bracing is not evident. From Charts 17 to 20, it can be seen that the maximum bending moment and shear force increases almost linearly for both vertical and plan bracing, with increase in water depth. This suggests that for welded tubular jacket structures, it would not be appropriate to treat the bracings as pure truss member, as they exhibit significant flexural forces in addition to axial forces.

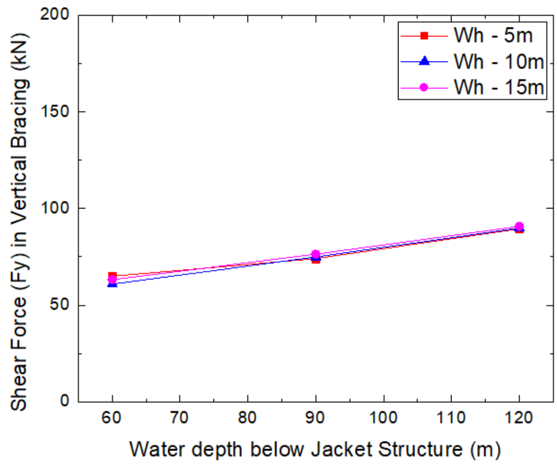

Chart - 17: Maximum shear force in vertical bracings of jacket structure

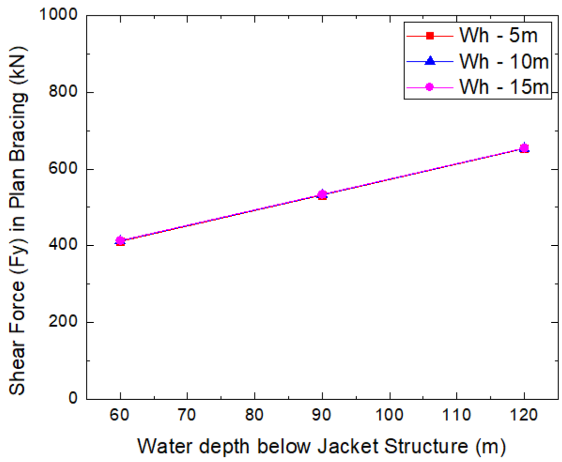

Chart - 18: Maximum shear force in plan bracings of jacket structure

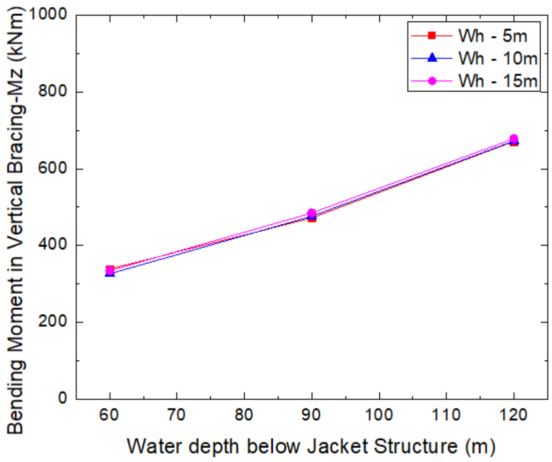

Chart - 19: Maximum bending moment in vertical bracings of jacket structure

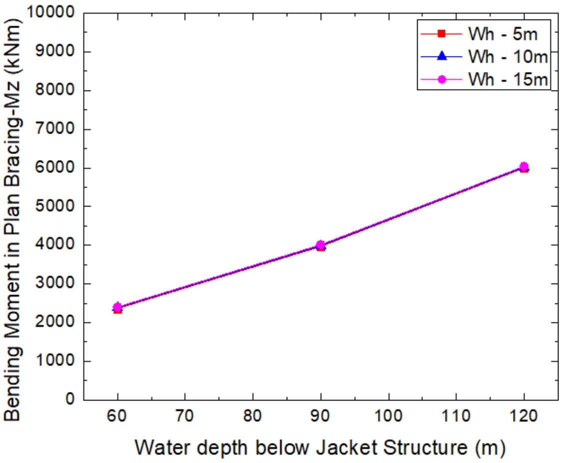

Chart - 20: Maximum bending moment in plan bracings of jacket structure

A summary of % variation in values of different parameters such as lateral and vertical deflection, support reactions and member forces, when water depth changes from 60m to 120m and when wave height changes from 5m to 15m, has been presented in Table 2.

Table - 2: Summary of response of jacket structure

PARTICULARS OF STRUCTURAL RESPONSE FOR JACKET STRUCTURE	% VARIATION BETWEEN:	
	60m and 120m WATER DEPTHS	5m and 15m WAVE HEIGHTS
LATERAL DEFLECTION	284	66
VERTICAL DEFLECTION	139.6	0
MAX. VERTICAL SUPPORT REACTION	59.4	12.2 (negligible)
MIN. VERTICAL SUPPORT REACTION (w/o deck loads)	102.1	17.4
HORIZONTAL SUPPORT REACTION	44.2	17.8
SUPPORT MOMENT	57.6	26.15
LEG-AXIAL FORCE	65.6	12.1 (negligible)
BEAM-AXIAL FORCE	0	0
LEG-BENDING MOMENT	138.6	2.84 (negligible)
BEAM-MAJOR BENDING MOMENT	126.2	0
LEG-SHEAR FORCE	101.7	2.34 (negligible)
BEAM-VERTICAL SHEAR FORCE	50	0
BEAM-HORIZONTAL SHEAR FORCE	0	72.3
BEAM-MINOR BENDING MOMENT	11.8 (negligible)	74.7
VERTICAL BRACING-AXIAL FORCE	0	42
PLAN BRACING-AXIAL FORCE	-32	0
VERTICAL BRACING-SHEAR FORCE	37.8	0
PLAN BRACING-SHEAR FORCE	59	0
VERTICAL BRACING-BENDING MOMENT	102.9	0
PLAN BRACING-BENDING MOMENT	151.4	0

Note: Positive and negative values in Table 2 indicate the increase and decrease in the parameter response value of jacket respectively.

4. CONCLUSIONS

The following conclusions can be obtained from this study:

1. The maximum lateral deflection of jacket structure increase almost linearly with increase in both water depth and wave height, while maximum vertical deflection increases in linear pattern with water depth.

2. The maximum vertical and horizontal support reactions are linearly proportional to water depth, while they show less variation with increase in wave height. The support moment seems to be linearly proportional to both water depth and wave height.

3. The maximum shear force and bending moment for jacket leg and beam increases (linearly) with water depth, while no significant change is observed with increase in wave height. For jacket

leg, the maximum axial force increases with water depth, while for beam, axial force appears to be independent of water depth as well as wave height.

4. The minor axis shear force and bending moment increases with increase in wave height, due to the fact that the increase in the wave load increases the local design forces for the beams, especially for the beams above water level.

5. Less variation is observed for maximum axial load in vertical and plan bracing with change in water depth and wave height. However, the maximum shear force and bending moment increases with increase in water depth. This suggests that the bracings are not behaving as pure truss members and needs to be designed as flexure members with axial load.

The study presents the effect of different water depths and wave heights on behaviour (deflection, support reactions and member forces) of offshore jacket structure.

The study can be extended to account for the effect of seismic forces also in future.

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