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Comparative Study of Braced Monopod and Tripod Jacket Offshore Platforms

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ABSTRACT

Safety and economic aspects become the most important issues in the oil and gas industry. Therefore, the exploitation process of oil and gas does not only require a safe structure but also a highly efficient structure especially for a marginal field. Today, jacket fixed offshore platform becomes the main choice as one of important facilities in the exploitation process. In this paper, structural design and reliability analysis based on collapse failure mode for three (3) different types of offshore fixed platforms, they are braced monopod and tripod jacket with one (1) vertical leg, and tripod jacket without vertical leg are conducted based on API RP2A WSD. In this study, it is found that for the same loading conditions, braced monopod is more efficient than the tripod jacket with respect to material used, installation cost, and also has lower probability of failure. From sensitivity analysis due to soil capacity, it is shown that the structure with no vertical piles has better performance than the structure with vertical piles.

Keywords:
Jacket offshore platform, braced monopod, tripod, structural reliability

1. Introduction

The exponential growth of oil and gas industry in the few last decades made offshore oil and gas exploration and production become a remarkably growing field. This reason also increased the number of offshore platforms around the globe. However, many challenges have to be faced by engineers, who design and analyze the offshore platform, due to the harsh environmental condition and high consequence of failures of the structures. Many researches have been done, and codes being developed in this field to fulfil the industry's needs and requirements.

The main concerns in design and analyses process of offshore structures are the safety and economic aspects. The most common types of structures used in the marginal field are either braced monopod or tripod since these types of structures are proved to be more economical. However, due to the lack of redundancy of monopod and tripod, both structures are susceptible to settlement caused by decreasing soil capacity during drilling operations. This study conducted the sensitivity analysis to investigate the effect of settlement on soil axial capacity of each type of structure.

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In order to obtain the additional information regarding the inherent characteristics and advantages comparison between braced monopod and tripod structures, a thorough study needs to be performed. Reliability levels of these two types of structures obtained by probabilistic reliability analysis are also required to gain the information about the structural integrity. To obtain a reliable comparison results, the random variables existing in these two types of structures should be made to be equal. Moreover, while the structures are designed complying to practical codes such as API RP2A-WSD [1] or API RP2A-LRFD [2], which is based on component-based design principles, the reliability analyses regarding the structural capacity as a whole should be done. This is called as system-based analyses, meaning that components of the structures are allowed to behave plastically, as long as it doesn't cause the structural instability. This kind of analyses is considered to give a better picture of the real structural capacity as a whole. Cost analyses regarding the total materials weight, engineering design, and the time needed for construction and transportation is also of interest in comparing different structural types.

2. Methodology

In this research, comparison study among braced monopod and 2 (two) tripod structures with different leg configuration were performed. The first step was structural design process, in which structures were designed and optimized to satisfy API RP2A WSD code of practice requirements regarding the in-place, seismic, fatigue, and pushover analyses. The resulted structural models were then used for subsequent reliability analysis accounting for the yield stress and wave height uncertainty. A sensitivity analysis was performed to determine the structural settlement sensitivity to axial soil capacity. The costs for design engineering, fabrication, installation, and transportation were then compared for all structures. The methodology for this paper is depicted in a flow diagram in Figure 1.

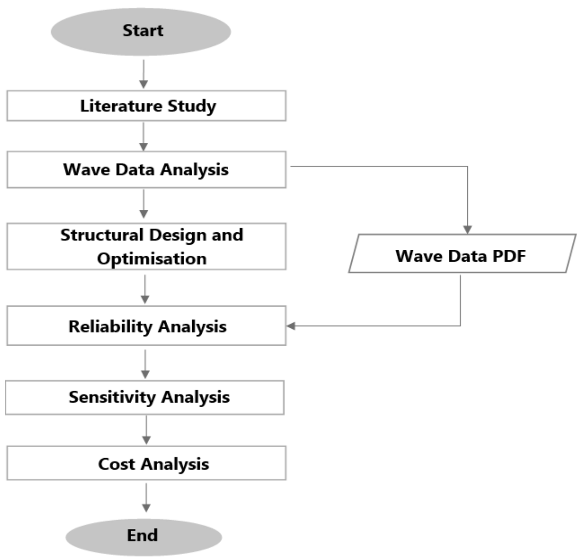

Fig. 1. Flow Diagram of Methodology

2.1 Environmental Data

The environmental data (wind, wave, current, and tide) to be used for this paper is a secondary data obtained from reliability research in Java Sea, Indonesia [10].

2.2 Structural Model

3 (three) types of structures with the same topside and site characteristics were to be considered in this research. They are braced monopod and 2 (two) tripods with different legs configuration. The topside structure with the associated equipment loads and live loads obtained from an existing structural model were used to provide a realistic behavior of the structure. The structures were designed and optimized based on API RP2A WSD including the maximum dynamic natural period criteria of 3 seconds. The analyses involved in designing the supporting structures were in-place, seismic, and fatigue analyses. The structural design and optimization is based on the commercially available cross section, where diameter in steps of 2 inches and the wall thickness in steps of 0.125 inch [11]. The structural models used in this paper is depicted in figure 2.

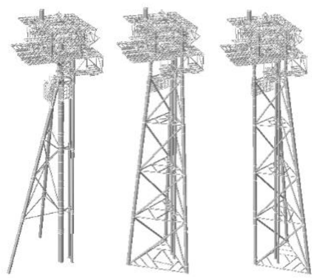

Fig. 2. Structural Model of Braced Monopod (Left), Tripod without Vertical Leg (Middle), and Tripod with One Vertical Leg (Right)

3. Reliability Analysis

Reliability analysis is started by determining performance function that defines the parameter of structure failure mode. Structure failure mode can be defined based on pushover/collapse [6,8], joint fatigue [7], fracture mechanics [9], and structural member failure [5].

Structural reliability analysis in this paper is performed based on structural collapse failure mode with wave data and structural yield stress as random variables. The structural collapse analysis (pushover analysis) is carried out by using SACS structural analysis software. Therefore, the performance function for reliability analysis is based on the base shear ratio (collapse base shear/wave base shear) as follows,

$$Base\ Shear\ Ratio = \frac{Collapse\ Base\ Shear}{Wave\ Base\ Shear} = 1 \quad (1)$$

Failure is defined as base shear ratio less than 1, from which probability of failure can be calculated as the ratio of failure occurrences to the total number of simulations. The reliability index (β) can be calculated from the resulting probability of failure (p_f) by using the following equation [4],

$$\beta = \Phi^{-1}(1 - p_f) \tag{2}$$

Φ^{-1} = Inverse of standard normal cumulative distribution function

The Monte Carlo simulation technique was used in order to determine the structural reliability. Before the reliability analyses was carried out, the probabilistic and statistical parameters of the random variables were determined. The random variables to be considered were the wave height and yield stress, while other parameters were assumed to be deterministic. The wave height has statistical mean of 17.814 feet, standard deviation of 3.3861 feet, with lognormal distribution type. The yield stress is regarded to have a lognormal distribution with COV of 6% as given by Det Norske Veritas [3]. The yield stress used for preceding analyses is 50 ksi, in which 5th percentile principle holds. The mean yield stress is 55.28 ksi. The reliability analysis flow diagram is depicted in figure 3.

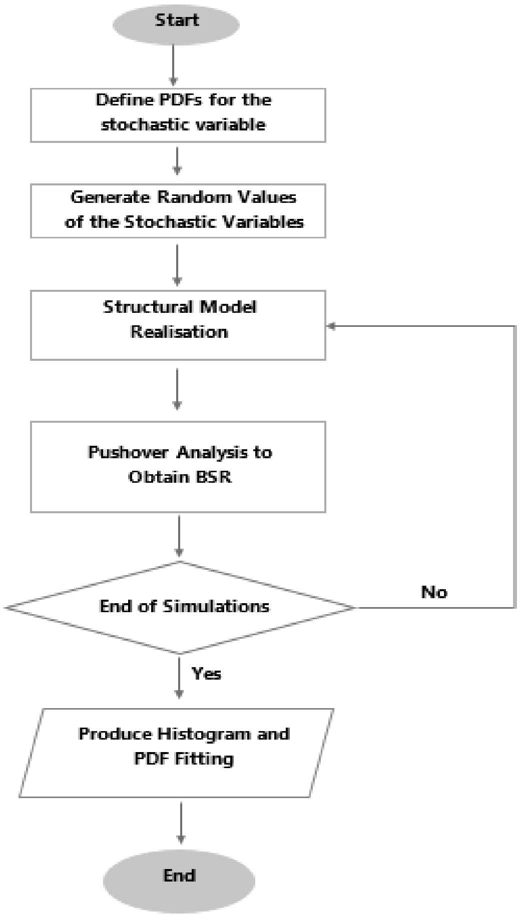

Fig. 3. Reliability Analysis Flow Diagram

The results of reliability analysis are summarized in Table 1.

Table 1
Reliability Index for All Structures

No.	Wave Direction (degree)	Braced Monopod		Tripod (Without Vertical Leg)		Tripod (One Vertical Leg)	
		β	p_f	β	p_f	β	p_f
1	0	INFINITY	1.88E-23	6.489454	4.30E-11	7.03716	9.81E-13
2	90	INFINITY	9.43E-31	6.8068929	4.98E-12	6.99954	1.28E-12
3	180	INFINITY	1.93E-25	7.3526680	9.71E-14	7.94144	9.74E-16
4	270	INFINITY	1.09E-26	6.6511825	1.45E-11	7.59006	1.60E-14

From the reliability analysis results, it can be observed that braced monopod has the higher reliability index than the tripod structures.

4. Sensitivity Analysis

During oil and gas exploitation, the soil below the mudline might be disturbed due to cavity introduced by the drilling operation. Environmental load which act laterally in periodic manner to the structure can cause lateral capacity failure. These cases, which is depicted in Figure 4, can reduce the soil capacity to withstand the external loads. In this research, the sensitivity analysis was performed for each pile settlement to all soil axial capacities, and for each pile to its corresponding soil axial capacity. The analysis is performed by reducing a particular pile's soil axial capacity to a certain percentage and observing the pilehead settlement due to external loads. Sensitivity analysis is performed for storm condition as the extreme case by using SACS structural analysis software.

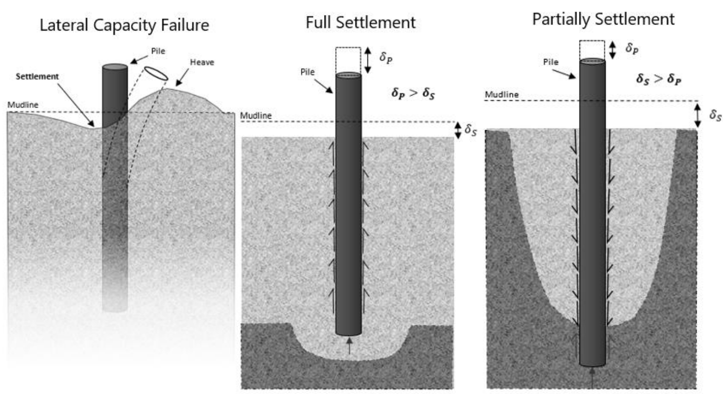

Fig. 4. Possible Soil Failure Mechanisms on Offshore Structures

The structural models with the corresponding pilehead codes are depicted in figure 5.

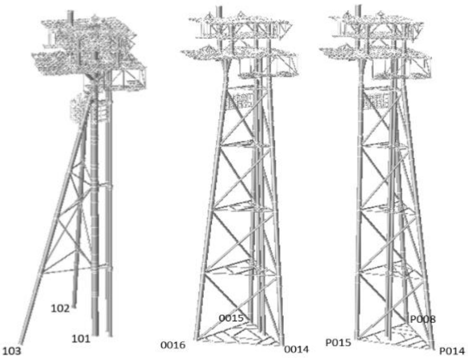

Fig. 5. Structural Models with Pilehead Codes: Braced Monopod (Left), Tripod without Vertical Leg (Middle), Tripod with One Vertical Leg (Right)

The sensitivity analysis results plots are depicted in figure 6, 7, and 8 for braced monopod, tripod without vertical leg, and tripod with one vertical leg respectively.

- Braced Monopod

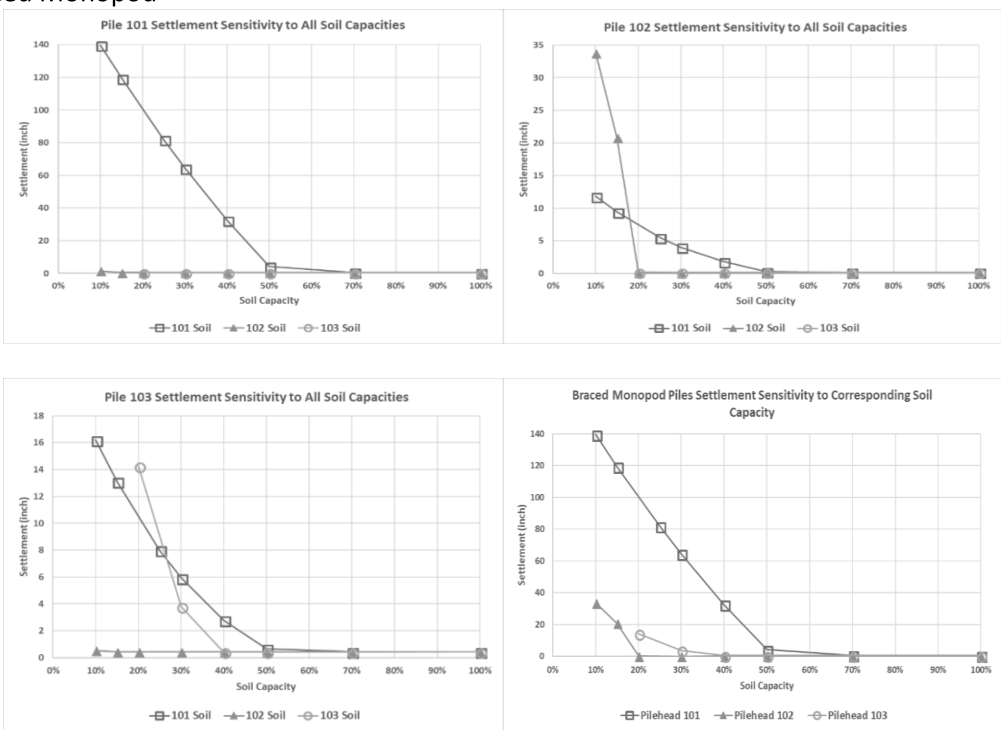

Fig. 6. Braced Monopod Sensitivity Analysis (Storm Condition)

- Tripod without Vertical Leg

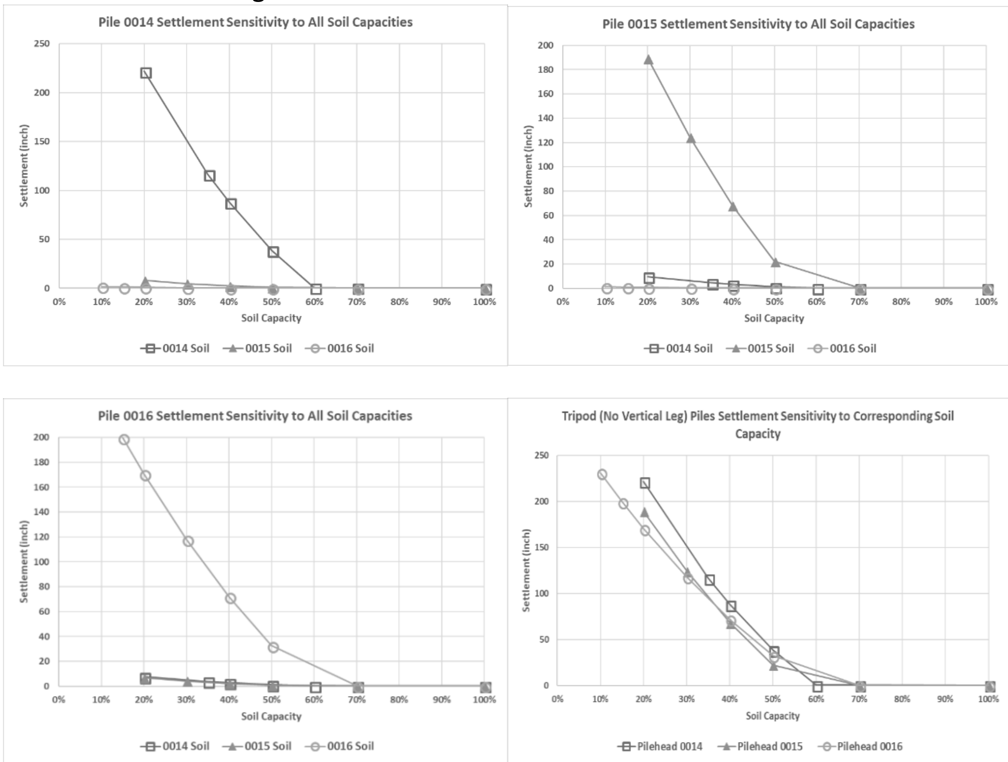

Fig. 7. Tripod without Vertical Leg Sensitivity Results (Storm Condition)

- Tripod with One Vertical Leg

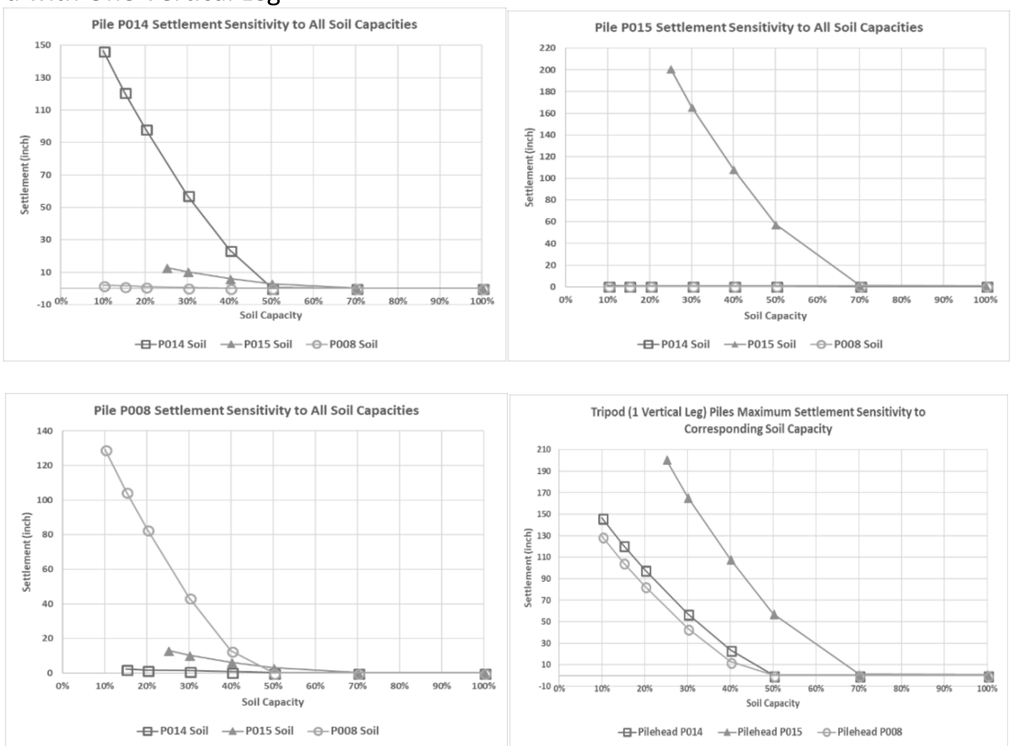

Fig. 8. Tripod with One Vertical Leg Sensitivity Analysis (Storm Condition)

From the above sensitivity analysis results (figure 6-8), it can be observed that for braced monopod all pilehead settlements are the most sensitive to vertical leg and the maximum settlement of pilehead due to its corresponding axial soil capacity reduction is most dominated by vertical leg. For tripod without vertical leg, the pilehead settlements are the most sensitive to the corresponding soil capacity, and the maximum settlement of pilehead due its corresponding axial soil capacity reduction is distributed more uniformly across all the pileheads. Tripod with one vertical leg exhibits the combination of braced monopod and tripod (without vertical leg) behaviors with respect to the settlement sensitivity.

5. Cost Analysis

In this study, cost calculation was performed for substructure and deck structure, neglecting conductor and production facilities cost. The base price was obtained from a cost estimation project performed by a consultant firm on offshore jacket platforms. The summary of cost analysis results is shown in Table 2.

Table 2
Cost Analysis Summary for All Structures

Description	Amount (USD)		
	Braced Monopod	Tripod 0 Vertical Leg	Tripod 1 Vertical Leg
Design Engineering	$661,318.14	$745,750.67	$729,424.77
Material	$1,033,355.07	$903,936.39	$1,030,846.43
Fabrication and Assembly	$938,135.65	$1,054,952.29	$1,055,078.24
Installation	$5,346,000.00	$6,204,000.00	$5,940,000.00
Transportation	$948,986.04	$1,158,994.70	$1,091,885.01
Total	**$8,927,794.90**	**$10,067,634.05**	**$9,847,234.45**

6. Conclusions

This paper performed comparison among braced monopod and tripod structures, that were designed and optimized with the same design criteria and procedure, in term of reliability index for 0,90,180, and 270 degrees angle wave attack direction, pile head settlement sensitivity to soil axial capacity, and cost regarding material, fabrication, installation, transportation, and engineering design. The conclusions drawn from this work are summarized in the following points:

- From reliability analysis, it is found that under the same design procedure and criteria, and despite of being designed and optimized with the same procedure and criteria and have the same natural periods (2.91-2.99) the designed braced monopod has lower probability of failure than the designed tripod structures.
- Sensitivity analysis of pile head settlement to soil axial capacity was performed for all structures. Both braced monopod and tripod with one vertical leg sensitivity are mostly concentrated on the vertical pile, while tripod without vertical leg has a more evenly distributed sensitivity across the piles. It is also found that all battered piles of braced monopod and tripod with one vertical leg are the most sensitive to vertical pile's soil axial capacity, while all piles for tripod without vertical leg are the most sensitive to its own corresponding soil axial capacity.

- From cost analysis, it can be observed that tripod (0 vertical leg) has the highest total cost, and braced monopod has the lowest total cost.

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