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THE EFFECT OF WAVE IN-DECK IN CONVENTIONAL PUSHOVER ANALYSIS

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Abstract. Subsidence is not a local settlement and one of the phenomena that may be experiencing by the offshore platform throughout the platform life. Compaction of the reservoir can cause it due to pressure reduction resulted to vertical movement of soils from the reservoir to mudline. The impact of subsidence on platforms will lead to a gradually reduces wave crest to deck air gap (insufficient air gap) and causing the Wave-in-Deck (WID) on platform deck. The WID load can cause a major consequence damage to the deck structures and potential to the collapse of the entire platform. The aim of this study is to investigate the impact of WID (with and without load) on structure response for fixed offshore structure. The usual run of pushover analysis only considering the base 100-years design crest height for the ultimate collapse. Thus, by calculating the wave height at collapse using a limit state equation for probabilistic model can give a significant result for WID. It is crucial to ensure that the Reserve Strength Ratio (RSR) is not overly estimated hence giving a false impression of the value. This study is performed in order to quantify the WID load effect on producing the new revised RSR. Finally, a parametric study on the probability of failure (POF) of the platform will be performed. As part of the analysis, the USFOS Software (Non-linear) and wave-in-deck calculation as suggested by ISO 19902 as practice in the industry are used in order to complete the study. It is expected that the new revised RSR with the inclusion of WID load will be lower hence increases the POF of the platform. The accuracy and effectiveness of this method will assist the industry, especially operators, for the purpose of decision-making and, more specifically, for their outlining of action items as part of their business risk management.

1 INTRODUCTION

In Malaysia, the offshore oil and gas industry is more than 100 years old. Its youthful economic exuberance has now given away to middle-aged restraint as the price of oil has fallen and field-development and operating costs have risen. In finding ways of managing the various financial risks, together with hydrocarbon exploration and production at sea, the structural reliability assessment has introduced, i.e., a rational method of putting the economics and engineering of offshore structures into a context that takes due account of uncertainties, particularly those connected with severe ocean storms [1].

Offshore jacket platforms are commonly used in the oil and gas production in the shallow water depths of Malaysia. Over 250 installations have been operating for more than 20 years [2]. 48% of these platforms have already exceeded 25 years reaching their initial design life of 20 to 25 years [3]. In view of the continuous production required beyond the design life, life extension of these installations is inevitable.

Development of the energy sector specifically in oil and gas with resources becoming scarce and challenging, added with growing development cost, has demanded oil and gas companies to enhance the recovery of oil and gas resources from developed fields and/or develop new discovery reserves from existing oil and/or gas platforms. In some cases, with several contributing success factors, this approach has proven to give a significant reduction in development costs, resulting in good project economics, making it viable to recover more oil and gas resources [4].

This paper is composed of 6 sections. Section 1 presents the introduction of oil and gas scene in Malaysia, followed by a brief review of wave-in-deck related to offshore platforms in Section 2. Section 3 described the methodology of calculating the reserve strength ratio of the platform and followed by the test structure specification in Section 4. The comparison of results is presented in Section 5 and lastly the conclusion and recommendation based on presented results in Section 6.

2 WAVE-IN-DECK AND RESERVE STRENGTH RATIO REVIEW

Wave-in-deck (WID) occurs when there is no deck clearance or air gap between the water level and bottom steel of topsides structure when it hit by the waves. Hence it should be considered in the analysis to avoid underestimate of the extreme tether tension. [5] All offshore platform which having WID need to be adequately designed by including the WID loads, especially the topside framing and the equipment seated on the deck. Furthermore, failure of considering the WID might lead to a collapse of the platform [6].

Pushover analysis, also known as ultimate strength analysis is widely used in determining the reserve strength ratio (RSR) of an offshore platform. The platform ability to withstand a specific environmental load will be checked, i.e. 100-years environmental loads, especially for an ageing platform. In view of complexity analysis, WID effect has been excluded in the conventional pushover analysis by only considering the 100-years crest height [7]. Figure 1 shows in view of the comparison between two (2) different approaches in industry, (b) where the impact of WID happens at the level of cellar deck of the platform.

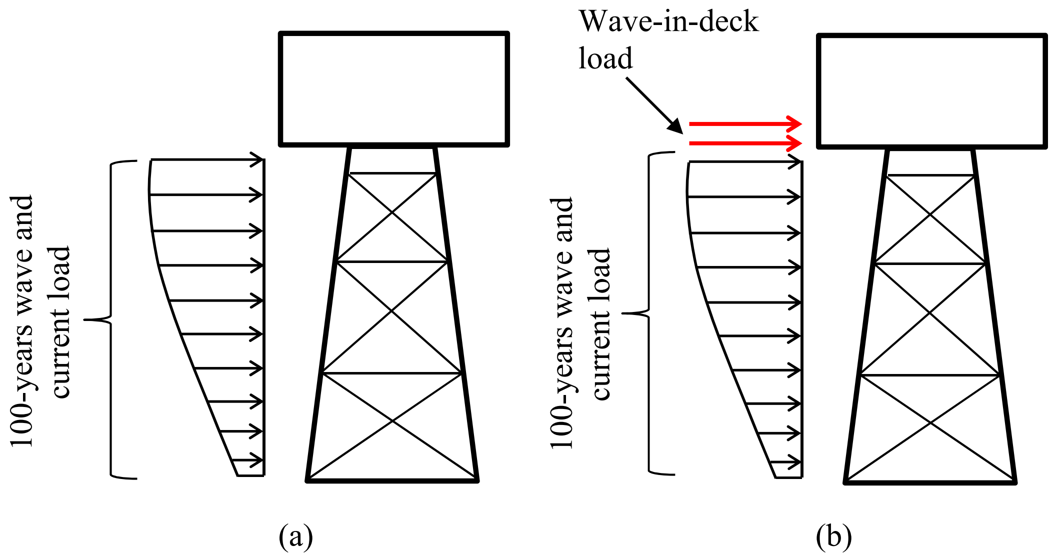

Figure 1: Comparison Between Conventional Method of Limiting the 100-years Wave and Current Load (a) versus the Inclusion of Wave-In-Deck Load (b)

The RSR of the platform is related to the physical wave height. It means that the associated wave height can be large enough to reach the deck structure. However, the conventional method involves the increment of the 100-years environmental load without considering the changing of the wave height [8]. The USFOS software that has been widely adopted for pushover analysis consider the wave forces up to true sea surface. The wave load is scaled up proportionally but not the wave height [9].

In order to summarize the sequence of event, Bow-Tie chart is introduced in this paper. The Bow-Tie is one of Health Safety Security Environment (HSSE) tool support for As Low As Reasonably Practicable (ALARP) [10]. As part of the Bow-Tie, structure strength and RSR determination are important elements of control barrier in order to avoid for the platform submergence (Top event). Figure 2 shows the elements in Bow-Tie:

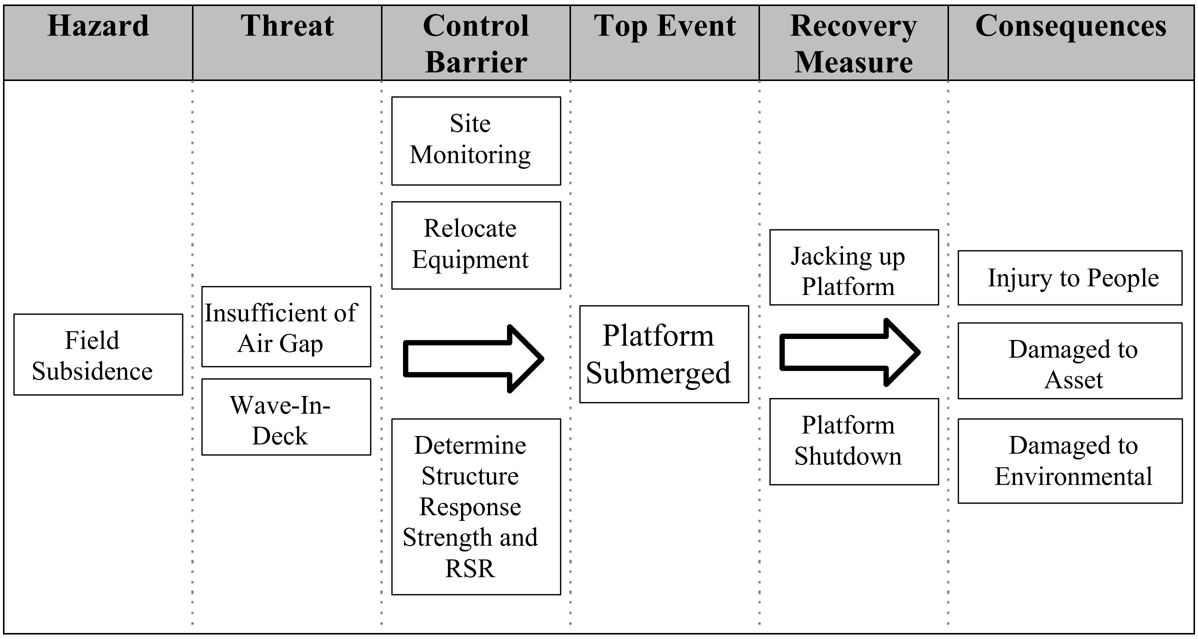

Figure 2: Bow-Tie of the Sequence

3 METHODOLOGY

In practice, the linear and non-linear analyses are implemented in this study with the base case and modified case. Begun with the base case run approach, in linear analysis with applying the original data from metocean and resulted in non-linear BS and RSR values at collapse. The H_{RSR} level is calculated from the limit state equation for probabilistic model as per Eq. (1);

$$H_{RSR}/H_{100} = RSR^{1/\alpha} \quad (1)$$

Basically, this study only considers wave in deck in horizontal directional impact. The modified case run approach is estimated wave crest height at cellar deck for re-linear analysis prior to re-non-linear analysis. As part of the analysis, the Silhouette (ISO 19902) approach has considered for representing the wave/current action load on topside, $E_{topside}$ as defined below

$$E_{topside} = \frac{1}{2}\rho_w C_d(\alpha_{wk}U_w + \alpha_{cb}U_c)^2 A \quad (2)$$

where

ρ_w = is the density of sea water
U_w = is the fluid velocity
U_c = is the current speed in line with the wave
α_{wk} = is the wave kinematic factor (0.88 for tropical cyclones and 1.0 for winter storm.
α_{cb} = is the current blockage factor for the structure

In preparation of the non-linear pushover analysis, the latest analysis SACS model has used analysis. The method of calculating the RSR of the platform is presented in the flowchart below:

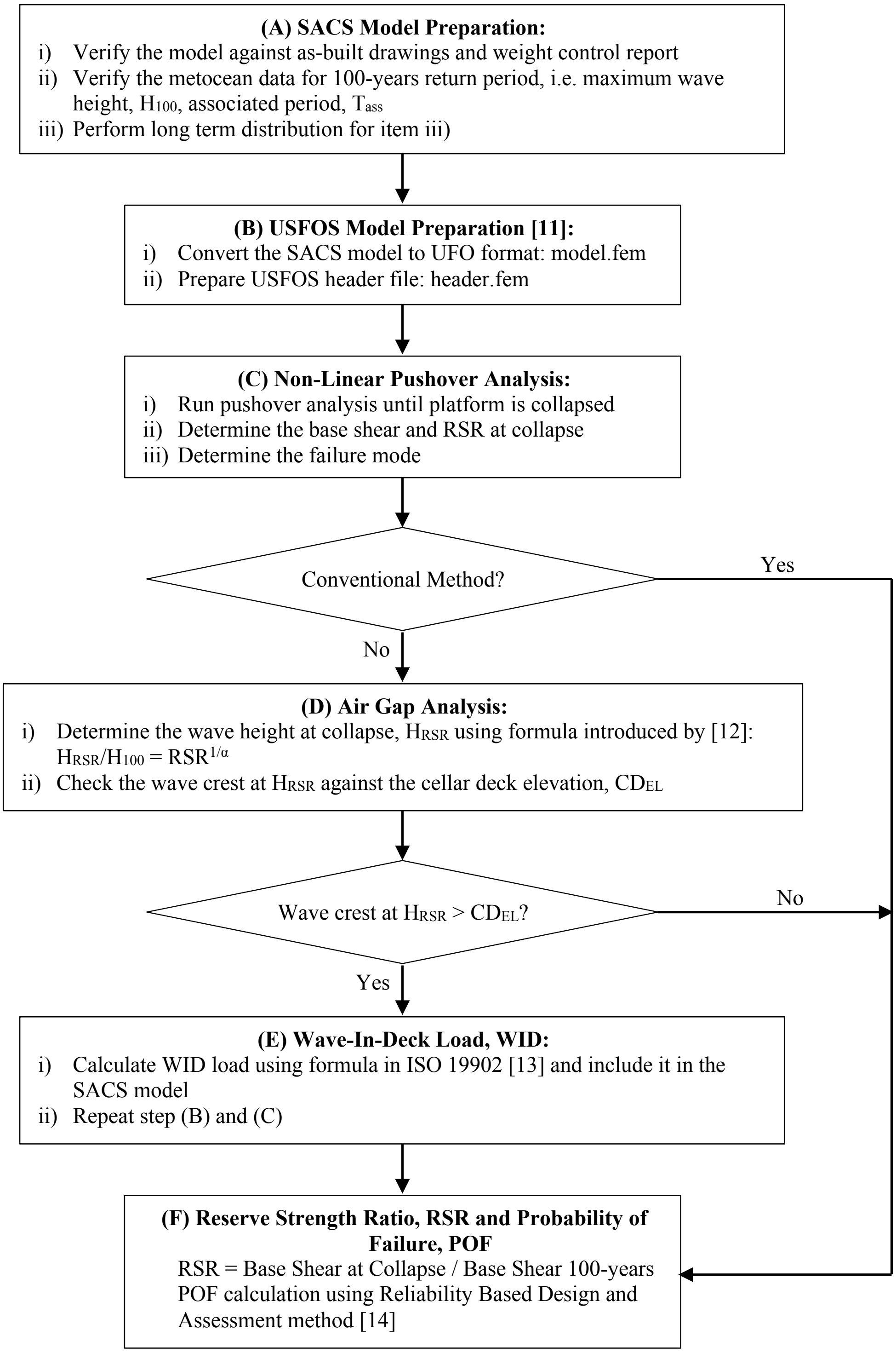

Figure 3: Flowchart of Analysis Procedure

4 TEST STRUCTURE SPECIFICATION

The test structure is an ageing compression fixed template platform with a water depth of 88.9m during installation. The general outline of the platform is shown in Table 1 and Figure 4. This platform has been selected due to the subsidence event that takes place throughout the platform life. Based on the subsidence report, there is a potential of WID occurrence due to a high level of subsidence at the area.

Table 1: Platform Specification

Features	Description
Field	Sarawak (Malaysia)
Design Service Category	Compression
Design Safety Category	Manned
Installed	1999 (18 years)
Water Depth During Installation	88.90m
Projected Water Depth at the year 2024	Minimum: 94.36m Maximum: 95.79m
Platform Orientation	Platform North, PN is orientated at 30° (clockwise) relative to True North, TN
Deck Configuration	MSF Deck (+23.40m) & Cellar Deck, CD (+15.80m)
Platform Brace Type	Vertical diagonal brace
Leg	4 with diameter of 1485.9mm and 19.05mm thickness, grouted annulus
Number of Pile	4 with diameter of 1371.6mm and 3.81mm thickness, 109.8 m penetration below mudline
Number of Caisson	2
Bridge Link	2, located at platform West and East

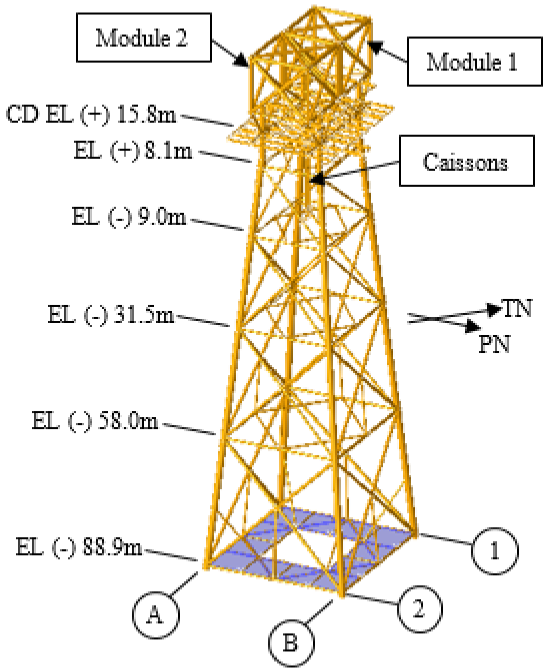

Figure 4: SACS Computer Model

The platform is modelled and verified using Structural Analysis Computer Software (SACS) computer program. The pile-soil-interaction, PSI was also modelled as it would also affect the RSR of the platform [15] in term of P-y, T-z and Q-z. Afterwards, the non-linear pushover analysis will be performed using USFOS computer program as described in Section 3.

5 COMPARISON OF THE RESULT FOR WITHOUT AND WITH INCLUSION WAVE-IN-DECK

In this section, the result between the methods is tabulated in detail. Omnidirectional metocean data is selected for the pushover analysis. Eight (8) direction corresponding to 0°, 47°, 90°, 132°, 180°, 227°, 270° and 312° were performed to the test structure. It is derived from the result of Metocean data analysis and was provided in this case study. The Metocean data was derived using existing HINDCAST data and it is based on deep water hydrodynamic [14].

5.1 METOCEAN DATA AND ASSESSMENT WATER DEPTH

Metocean data and water depth for 100-years return period are tabulated in Table 2 below. The sensitivity of minimum and maximum water depth need to be performed beforehand.

Table 2: Metocean Data and Water Depth for 100-Years Return Period

Wave Height (m)	
Hmax	11.6
Wave Period (s)	
Tass (lower)	10.1
Tass (Central)	11.3
Tass (Upper)	12.4
Associated Current (m/s)	
1.00d, Surface	0.900
0.90d	0.828
0.80d	0.756
0.70d	0.684
0.60d	0.612
0.50d	0.540
0.40d	0.475
0.30d	0.456
0.20d	0.430
0.10d	0.389
0.06d	0.351
0.04d	0.243
0.02d	0.118
0.00, Seabed	0.000

Wind Speed at 10m from MSL (m/s)	**V (1-hr)**	**V (1-min)**
Wind Speed	15.0	20.7

Water Level (m)	**Minimum**	**Maximum**
Mean Sea Level, MSL at Year 2024	94.36	95.79
Highest Astronomical Tide, HAT	-	0.9
Lowest Astronomical Tide, LAT	-1.2	-
Surge	-	0.6
Inaccuracies of Water Depth	-0.94	0.95
Assessment Water Depth	92.22	98.24

5.2 RSR AND H_{RSR} DETERMINATION

The outcome from the pushover run using USFOS Software, Table 3 below shows the result of each omnidirectional without the inclusion of wave-in-deck. It is conventional approach with the normal process of determination of RSR, H_{RSR} and Wave Crest.

Table 3: RSR, H_{RSR} and POF without Inclusion of Wave-In-Deck

Run No.	Dir. (°)	RSR	Base Shear at Collapse (kN)	H_{RSR} (m)	Wave Crest at H_{RSR} (m)	Probability of Failure, POF
1	0	5.58	24217.31	31.89	111.93	*
2	47	5.94	22186.96	33.08	112.79	*
3	90	5.92	20365.43	33.02	112.77	*
4	132	6.14	22645.99	33.74	113.28	*
5	**180**	**4.74**	**21140.49**	**28.97**	**109.85**	**3.65E-04**
6	227	5.87	22179.10	32.85	112.64	*
7	270	6.44	22553.59	34.70	114.00	*
8	312	6.86	24850.19	36.01	114.94	*

* Only the POF of the lowest RSR is calculated.

The distance of the cellar deck bottom of steel, BOS from the mudline is 103.79m, hence all cases having wave crest at H_{RSR} higher than the BOS. Lowest RSR which is run no. 5 (at 180° omni directional) is selected for further analysis by considering the wave-in-deck load. Refer Table 4 below for revised RSR and POF:

Table 4: RSR and POF with Inclusion of Wave-In-Deck

Run No.	Dir. (°)	RSR_{WID}	Base Shear at Collapse (kN)	Probability of Failure, POF_{WID}	Remark
5	180	4.54	20234.25	4.54E-4	$RSR_{WID} < RSR$ $POF_{WID} > POF$

6 CONCLUSION

From the result above, it can be concluded that an assessment is completed when satisfactory compliance with respect to RSR_{WID} is less than RSR and following conclusions can be drawn;

- The $RSR_{with\ WID}$ is lower compared with $RSR_{without\ WID}$ i.e. 4.54 < 4.89 while $POF_{with\ WID}$ is higher compared with $POF_{without\ WID}$ i.e. 4.54E-04 > 3.65E-04. Thus the result is acceptable.
- It is crucial to consider the wave-in-deck loads in the pushover analysis hence to avoid overestimation in the value.
- Even though that the wave-in-deck load was difficult to predict, it cannot be ignored totally hence giving a false impression and will lead to a wrong judgement in later assessment.

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