

Wave-in-Deck Force on Fixed Jacket Platforms by Silhouette Method and Detailed Component Method



L. A. Pangestu, C. Y. Ng, A. E. Kajuputra, M. K. Muzammil and S. Sabtu

Abstract Wave-in-deck creates extra forces to the platform by increasing its moment arm which cause instability in terms of overturning. Fixed offshore platforms are generally not intended to withstand the substantial forces produced by wave-in-deck loads. Nonetheless, the requirement to accurately predict the magnitude of wave-in-deck forces and the platform global response of a jacket platforms in regards to current engineering knowledge and variance jacket platforms configuration remains limited. The research aims to compare API procedure, i.e. the silhouette method for predicting wave-in-deck force with detailed component method. Simulation study has been carried out and evaluate the wave-in-deck forces on two fixed jacket platforms installed in South China Sea using SESAM Software (GeniE and USFOS) by DNV GL and to quantify wave forces and the effect of wave-in-deck in terms of RSR on the jacket platforms. The results indicate that detailed component method has smaller reduction of RSR for platform A by 2.65% and platform B by 9.25% whereas silhouette method's reduction by 18.58% and 32.91% respectively.

Keywords Wave-in-deck · Fixed offshore platform · Ocean wave-structure interactions · Silhouette method · Detailed component method · RSR · Reserve strength ratio · Airgap · Pushover analysis

1 Introduction

There are more than 9000 fixed offshore platform for hydrocarbon production all around the world [1], about 200 jacket platform currently operating in South China Sea [2]. More than half of these platform in the area have exceeded their service life of 25 years. Therefore, reassessment of platform has to be performed to comply or ensure that the platform safety. The factor that affecting most jacket platforms

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are seabed subsidence caused by reservoir compaction, increased topside weight or operational loads, revised environmental criteria, reduced capacity due to damage, corrosion and deterioration. Seabed subsidence occurrence causing the platform to settle down and causing the wave-in-deck phenomenon. Wave-in-deck occur when the wave crest hit the top deck, this scenario is likely to occur when the platform has negative airgap, the space between the lower deck of the platform and the water surface. Therefore, this phenomena is becoming more vulnerable to deck wave inundation.

The process of reassessment of the offshore platforms in an area often starts with a simplified evaluation of a larger number of platforms, proceeding to more detailed analyses for those platforms that do not fulfill relevant code requirements when being subject to simplified evaluation methods. If a platform fails to fulfill the requirements during the reassessment process, there are several alternatives for mitigation, such as increase topside elevation, removal of weight from topside or removal of conductors or risers, marine growth etc. to reduce environmental loads.

2 Wave-in-Deck

Wave-in-deck creates extra forces to the platform by increasing its moment arm which cause instability in terms of overturning. Fixed offshore platforms are generally not intended to withstand the substantial forces produced by wave-in-deck loads. On the off chance that a wave yet hits the deck, the deck legs, which are not estimated to exchange shear forces of this magnitude from the deck into the jacket platform, might be excessively loaded. Likewise, substantial upwards and downwards acting vertical loads might be presented in the platform, additionally decreasing the deck legs' ability to convey the transverse load. At last may likewise apply to the jacket legs. Subsequently, other failure modes than those considered during design phase can governing for platforms exposed to wave-in-deck loads.

So far there is no common engineering practice on how to model impact loading from waves on topside platforms. Several methods are previously used for this task, some verified against experimental data and some not. Reassessment of offshore platforms, particularly where wave-in-deck load is expected to simplified methods for wave-in-deck loads estimation recommended [3], are widely accepted in industry practice. The American Petroleum Institute (API) standard has the most commonly utilized methods and numerical formulations for wave-in-deck forces. The methods are divided into two fundamental groups, to be specific component models and global or silhouette models. The silhouette models are again subdivided into two groups, those based on loss-of-momentum formulation and on drag formulation.

There have been researches to find the most accurate method on how to determine wave-in-deck forces. Murray [4] conducted both experimental and analytical studies of wave impact forces to the Ekofisk platform, operated by Phillips Petroleum Company Norway. The fitness-for-purpose analysis of a platform using nonlinear methods or equivalent linear methods to determine the platforms global ultimate

capacity, often referred to as a pushover analysis [3] can also be utilized to determine wave-in-deck forces. Raaij and Gudmestad [5] studied both global and local approach to find the realistic time-load histories for jacket platforms in the North Seas.

In 2011, Incremental Wave Analysis (IWA) was introduced to produce an estimation of various limit states and precise performance of jacket platforms against wave loadings. Golareshani [6] claimed that this approach is more accurate to represent the actual behavior of a jacket platform against environmental wave loadings as alternative to the conventional pushover practice. The pushover analysis using 100-year storm return period and RSR parameter is unable to determine the real failure mechanism against wave loads, as well as the platform's response towards various wave hazard level.

Suyuthi and Haver [7] reported that, these simplified method could significantly underestimated the impact load in extreme conditions. Experimental model tests are arguably the best approach to access the wave-in-deck load [8]. However, model test also has its own limitations, such as scale effects and significantly high cost [9].

Variety of models exist, some of which have been more extensively examined than others [5]. The methods can be divided into two main groups; firstly the global or silhouette method and secondly the detailed component methods where the load on each single members is calculated separately. The 'detailed' methods require a detailed deck model and allow for calculation of wave-in-deck loads on component level [10, 11]. Where the silhouette method implies that no detailed deck model is needed formulated by API [3], ISO formulation [12], DNV slamming formulation [13].

2.1 Detailed Component Method

The Reserve Strength Ratio (RSR) from pushover analysis is the ratio between collapse load and the design load of 100 years storm. The design load is scaled up on the platform until it collapses, which realistically should be related to increment of wave height that may reach the deck and generates wave-in-deck forces. However, USFOS is not capable modeling of such phenomena of wave height increment during load increment in pushover analysis.

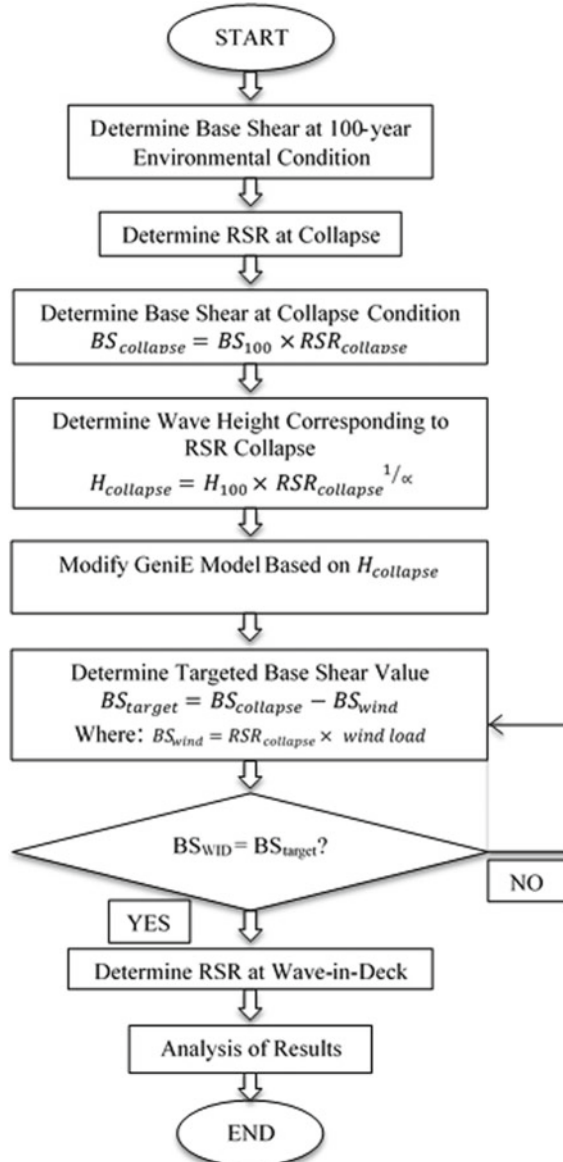
Wave-in-deck generates additional load from the deck with equipment being exposed and also increases moment arm to the platform. These consequently increase the overturning moment that influence the collapse load or capacity, which decreases the RSR value at the end.

The limiting RSR in extreme airgap analysis is the lower bound of the true ultimate RSR. The actual collapse RSR with wave-in-deck is obviously higher than the lower bound value but lower than the upper bound value of RSR collapse taken from pushover analysis without considering wave-in-deck.

This method which examine loading on each individual component on the topside platform. Higher drag coefficient (Cd) value applied on deck members inundated by

the waves following recommendation given by both API RP 2SIM [3] and ISO 19902 [12] in order to capture the additional loads from the equipment on the deck. The flow process of the numerical simulation is shown in the Fig. 1.

Fig. 1 Detailed component method



2.2 Silhouette Method

The drag based silhouette wave-in-deck models have in common the typical drag formulation known from Morison equation. The absolute value of the load as follows:

$$F_x = \frac{1}{2} \rho A C_d u_w^2 \quad (1)$$

where ρ is sea water density u_w is the water particle velocity, $A = s_d b$ is the exposed area, s_d is the inundation (height) and b the width of the inundated area. The drag factor C_d is chosen to account for different loading scenarios. These models are typically intended for calculation of maximum load, but the simple formulation makes them also easy to apply for time domain analyses, noting that the particle velocity u_w and the inundated area A are time dependent variables. In API RP 2SIM [3], the C_d values is varied between 1.2 and 2.5 according to the wave direction and the equipment density on the deck. The water particle velocity u_w contains a sum of current velocity and wave induced particle velocity, as well as a current blockage factor and a wave kinematics factor.

The deck force procedure relies on a calculated crest height. The crest height should be calculated using the wave theory using Two-Dimensional Wave Kinematics and the ultimate strength analysis wave height, associated wave period, and storm tide.

Given the crest height, compute the wetted “silhouette” deck area, (A) projected in the wave direction, (θ_w). The full silhouette area for a deck is defined as the shaded area in Fig. 2, the area between the bottom of the scaffold deck and the top of the “solid” equipment on the main deck. The area, A , is computed as follows:

$$A = A_x \cos \theta_w + A_y \sin \theta_w \quad (2)$$

where, θ_w , A_x , and A_y are defined in Fig. 2.

The wave-in-deck force, can be computed by the following:

$$F_{dk} = \frac{1}{2} \rho A C_d (a_{wkf} \cdot V + a_{cbf} \cdot U)^2 \quad (3)$$

where,

- U Current speed in-line with the wave
- a_{wkf} Wave kinematics factor (0.88 for hurricanes and 1.0 for winter storms)
- a_{cbf} Current blockage factor for the jacket
- ρ Mass density of seawater
- C_d Drag coefficient, given in the Table 1.

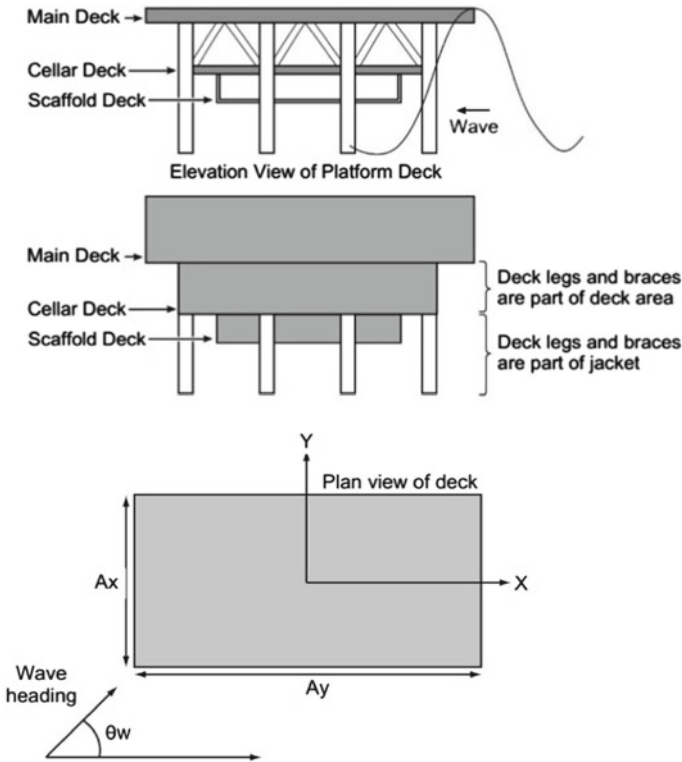


Fig. 2 Silhouette area definition & wave heading and direction convention [3]

Table 1 Drag coefficient (Cd) for wave-in-deck forces [3]

Deck type	Cd end-on and broadside	Cd diagonal (45°)
Heavily equipped (solid)	2.5	1.9
Moderately equipped	2.0	1.5
Bare (no equipment)	1.6	1.2

3 Data Collection

Data collection of the jacket platforms for the parameters identification and data selection are presented in Table 2. Table 3 shows the data collection of extreme airgap analysis spreadsheet of Platform A and B. The direction of 225° was chosen as critical direction based on the lowest RSR value of 1.83 with -3.11 m of airgap

Table 2 Platforms description

Model	A	B
Water depth (m)	29.87	75.4
Design service category	Production	Wellhead
Design safety category	Unmanned	Unmanned
Installed	1968	2016
No. of legs	4	4
No. of piles (mm Ø)	4 main (610) and 5 shear (1067)	4 (1372)

for Platform A and 315° as the critical direction of Platform B with -2.93 m of airgap.

4 Pushover Analysis

Figure 3 shows the isometric view of platform model Platform A and B. Simulations were done using SESAM GeniE and USFOS by modifying wave height and wave period based on the process shown in Fig. 1.

4.1 Detailed Component Method

Platform A has extreme airgap analysis results as shown in Table 3, that negative airgap appears at 0° , 90° , 135° , 225° , 270° and 315° metocean direction at RSR collapse condition. Negative airgap has already occurred prior to the approach of 100 years storm wave height for the critical direction (225°) with -3.11 m airgap and for 270° and 315° direction with -3.31 m and -3.01 m airgap, respectively. The storm 100 years wave height for 225° is 7.20 and 6.50 m for 270° and 315° . The limiting RSR after considering control to avoid wave-in-deck is 0.56 (reduced from 1.83) for 225° direction, which does not satisfy the minimum criteria 1.32 for unmanned platform.

Similarly for Platform B, the extreme airgap analysis results show that negative airgap appears at 0° , 180° , 270° and 315° metocean directions at collapse condition or at RSR value. The RSR value is then limited to the value when the zero airgap is reached to avoid wave-in-deck forces. The lowest RSR at 315° direction is then reduced from 3.89 to 2.40.

Wave-in-deck analysis using detailed component method were done to follow up the unsatisfactory results from extreme airgap analysis. Higher Cd value 1.9 is applied to the topside members for both platform considering heavy equipped topside as recommended for diagonal direction by ISO 19902 and API RP 2SIM.

Table 3 Extreme airgap analysis

Platform	A										B									
	N (45°)	NE (0°)	E (315°)	SE (270°)	S (225°)	SW (180°)	W (135°)	NW (90°)	SE (0°)	E (45°)	NE (90°)	N (135°)	NW (180°)	W (225°)	SW (270°)	S (315°)				
100-year wave height (m)	1.20	5.30	6.50	6.50	7.20	1.20	1.20	1.20	8.50	5.80	5.60	6.20	6.60	6.00	9.00	12.60				
RSR	5.97	2.23	2.12	2.3	1.83	9.3	13.34	19.56	7.91	6.38	10.19	7.55	10.00	7.30	7.74	3.89				
Cellar deck elevation (m)	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17	12.50	12.50	12.50	12.50	12.50	12.50	12.50	12.50				
1/2 of deck girder height (m)	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17				
Water depth from MSL (m)	29.87	29.87	29.87	29.87	29.87	29.87	29.87	29.87	75.40	75.40	75.40	75.40	75.40	75.40	75.40	75.40				
HAT (m)	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
Storm surge	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60				
Wave crest height factor	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55				
Wave height exponent	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00				

(continued)

Table 3 (continued)

Platform Direction	A										B									
	N (45°)	NE (0°)	E (31.5°)	SE (270°)	S (225°)	SW (180°)	W (135°)	NW (90°)	SE (0°)	E (45°)	NE (90°)	N (135°)	NW (180°)	W (225°)	SW (270°)	S (31.5°)				
Initial air-gap(m)	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06	10.74	10.74	10.74	10.74	10.74	10.74	10.74				
MSL + HAT + Storm surge (m)	31.61	31.61	31.61	31.61	31.61	31.61	31.61	31.61	31.61	77.00	77.00	77.00	77.00	77.00	77.00	77.00				
Bottom of cellar deck elevation (m)	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	87.74	87.74	87.74	87.74	87.74	87.74	87.74				
Wave height corresponding to RSR (m)	3.43	8.50	10.11	10.61	10.27	4.46	5.51	6.90	23.91	14.65	17.88	17.04	20.87	16.21	25.04	24.85				
Wave crest height (m)	2.06	5.10	6.07	6.37	6.16	2.67	3.31	4.14	13.15	8.06	9.83	9.37	11.48	8.92	13.77	13.67				
Crest elevation (m)	4.71	7.75	8.72	9.02	8.81	5.32	5.96	6.79	14.75	9.66	11.43	10.97	13.08	10.52	15.37	15.27				

(continued)

Table 3 (continued)

Platform Direction	A										B									
	N (45°)	NE (0°)	E (315°)	SE (270°)	S (225°)	SW (180°)	W (135°)	NW (90°)	SE (0°)	E (45°)	NE (90°)	N (135°)	NW (180°)	W (225°)	SW (270°)	S (315°)				
Airgap (m)	1.00	-2.04	-3.01	-3.31	-3.11	0.38	-0.25	-1.08	-2.41	2.68	0.90	1.37	-0.74	1.82	-3.04	-2.93				
Limiting RSR	11.68	0.93	0.66	0.66	0.56	11.68	11.68	11.68	5.27	11.32	12.15	9.91	8.75	10.58	4.70	2.40				

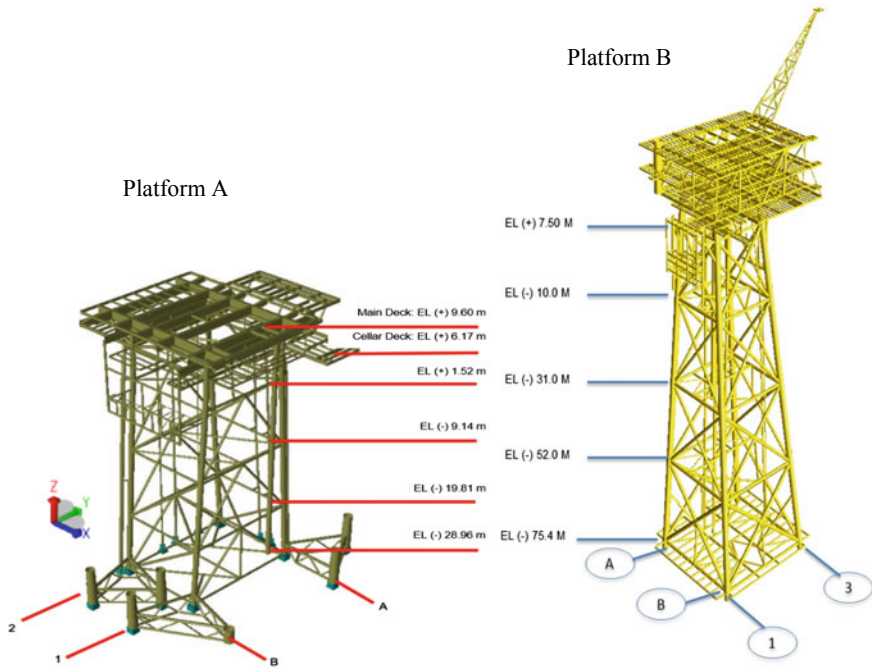


Fig. 3 Isometric view platform A and platform B

Joint probability metocean data (wave govern) is also applied in this wave-in-deck analysis considering the probability of occurrence of wave and current 100 years return period accordingly. The analysis results shows that RSR ultimate for Platform A at wave-in-deck condition is 1.78 with reduction ratio of 0.97 to the RSR collapse 1.83, and 3.54 with reduction ratio of 0.91 from RSR collapse of 3.89 for Platform B.

4.2 Silhouette Method

Figures 4 and 5 show the comparison between the collapse pushover analysis and wave-in-deck pushover analysis using Sihlouette Method for Platform A at 225° direction.

Based on Eq. (2), Platform A has silhouette area of 68.65 m² and wave force generated from 10.27 m of wave height taken from Table 3 is 357.07 kN, which has applied equally to each topside legs. The analysis result shows a quite significant reduction of RSR to 1.49 as shown in Fig. 5, compare to RSR collapse of 1.83 and RSR ultimate using detailed component method which is 1.78.

Fig. 4 Platform A 225° pushover analysis plot

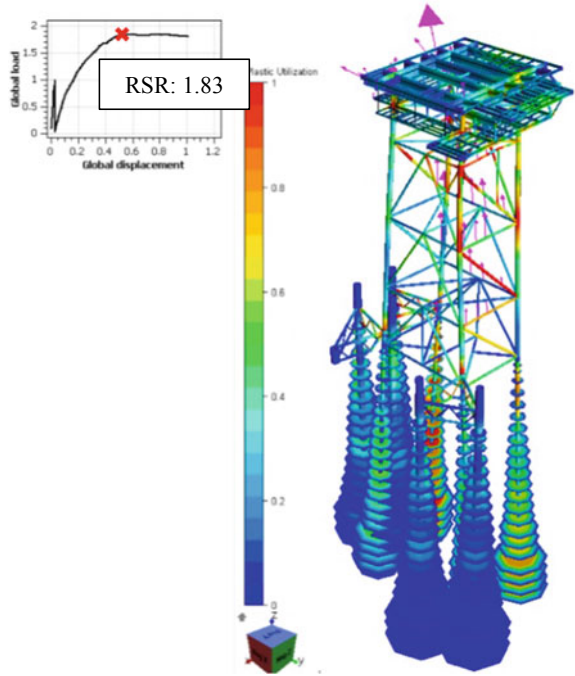
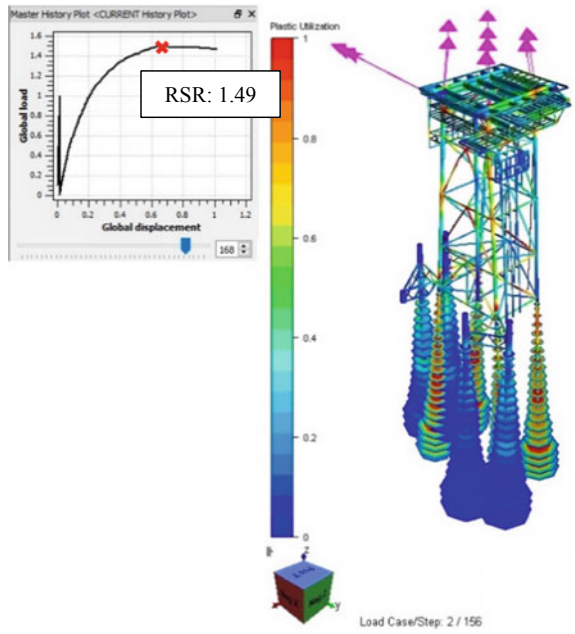


Fig. 5 Silhouette method platform A 225° wave-in-deck pushover analysis plot



On the other hand, Platform B received 981.34 kN to each legs from silhouette area of 79.34 m² with 24.85 m corresponding wave height, reducing RSR from 3.89 to 2.61 as shown in Figs. 6 and 7 respectively.

Fig. 6 Platform B 315° pushover analysis plot

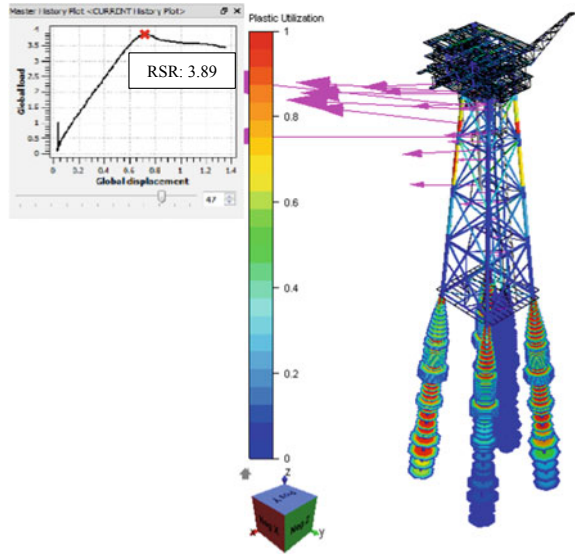


Fig. 7 Silhouette method platform B 315° wave-in-deck pushover

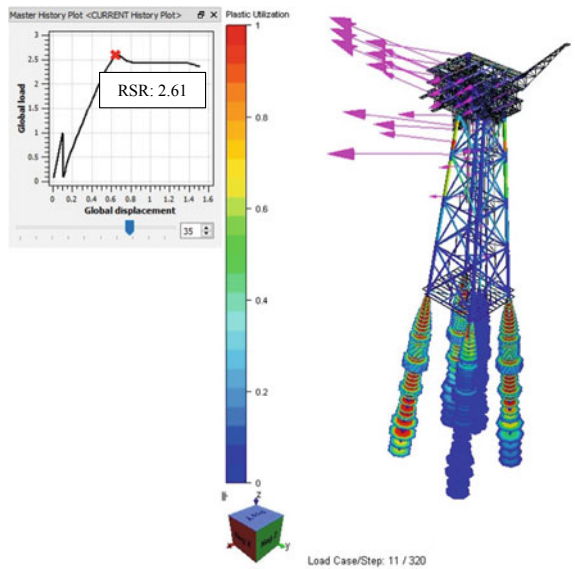


Table 4 RSR wave-in-deck results

Platform	A	B
RSR _{Collapse}	1.83	3.89
RSR _{Ultimate} DCM	1.78	3.54
RSR _{Ultimate} SM	1.49	2.61

5 Conclusions

This research studies the significance between silhouette method and detailed component method on wave-in-deck force estimation for fixed jacket platforms. It was identified that the current wave-in-deck analysis practice has no mutual concession approach.

As described on Table 4, the detailed component method result of Platform A shows there was RSR reduction by 3% from 1.83 to 1.78 and Platform B by 9% to RSR 3.54. Compared to silhouette method which has more substantial reduction for both platforms, RSR reduced from 1.83 to 1.49 for Platform A and RSR 3.89 to 2.61 for Platform B. Although, it is still satisfied the minimum acceptance criteria of 1.32 for unmanned platform.

The difference between silhouette method being lower than detailed component method is due to the overestimated wave force acting on topside as wave-in-deck force. The wave-in-deck forces computed in silhouette methods assumed that the deck exposed to the wave as a whole of block rectangular of silhouette.

As compared to detailed component method which simulated the wave exerted to the topside similar to jacket structures with higher drag coefficient (Cd) value representing the component installed on the topside.

Therefore, this results can indicate which method is more efficient and reliable. Industries can have more insight on which method is more reliable because there is no general consensus on analyzing wave-in-deck force towards offshore structure.

Other than that, by knowing the actual RSR of the platform without over estimation of the platform strength it can results in cost saving. It is because the RSR value will indicate whether underground inspection is required or otherwise. Hence, knowing real RSR value can save millions of ringgit with regards to maintenance works of offshore platform.

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