Pushover Analysis for Jacket Platform

Sensitivity Study and Safety Ratios

V.J. Kurian[1], M.M.A. Wahab[2], M. C. Voon[3],M. S. Liew[4]
Civil Engineering Department,
UniversitiTeknologi PETRONAS,
Bandar Seri Iskandar, Tronoh, Malaysia.
kurian_john@petronas.com.my[1], mubarakwahab@petronas.com.my[2]
voonminchin@gmail.com[3], shahir_liew@petronas.com.my[4]

***Abstract*—Most of the jacket platform in Malaysian water has exceeded their design life, mainly due to the demand of continue usage to further extract oil from the reservoir. Hence, the reliability of the jacket platform has to be assessed to ensure they are fit for future operation despite aging problem. Pushover analysis will be performed on jacket platform to obtain Reserve Strength Ratio as an indicator of the reliability of the jacket. The significance of parameters such as pile soil interaction, wave direction and platform's geometrywas studied in a sensitivity study. This paper discusses the parameters that bring significant effects on the value of Reserve Strength Ratio. Besides, author also assess the effect of damaged members on the platform's ultimate capacity and produce other safety indicator other than Reserve Strength Ratio to better describe the safety of a jacket platform.**

Keywords—Reliability; Pushover Analysis; Reserve Strength Ratio; Sensitivity Study

I. INTRODUCTION

PETRONAS CarigaliSdnBhd (PCSB) is currently operating about 200 jacket platforms. Of these over 60% have been in operation for more than 20 years, 20% of platforms have already exceeded 30 years with several others in the very near future reaching their initial design life of 20 to 25 years. With development of oil extraction technologies and further oil and gas fields' discovery, there are increasing demands to extend the life of these platforms. The scenario is that the jacket platforms being subjected to higher loading due to required modifications or upgrading and work-over-demands for which the platform may not been originally designed for [1]. An existing platform should undergo assessment process if there is addition of personnel, increased loading on structure, and damage found during inspection [2]. Furthermore, there are other challenges such as onerous code requirements; changes or increase in environmental met-ocean loading, presence of shallow gas and seismic or earthquake loading; again in which the platforms are not initially designed for. Therefore, there is a need to address the ongoing structural integrity of these platforms [1].

Lately some studies were conducted [3, 4] related to reliability of Malaysian jacket platforms as well as on the reliability of other types of platforms in the other parts of the world [5, 6, 7]. In late 90's, reliability approach was becoming the common practice in Malaysian oil and gas industry mainly due to better exposure to techniques, improvement in the computational system and better demand for such analysis. In fact, PCSB has a Risk Based Inspection (RBI) program which categories platform based on risk of failure and provides inspection recommendations accordingly. The current practice of RBI emphasized on the likelihood of structural collapse of a platform which is assessed from two factors namely: platform strength and extreme loading the platform is being exposed to. Pushover Analysis will provide RSR value to better assess the platform'sreliability [8].

Authors have conducted sensitivity studies on the parameters which affect the RSR in consideration of wave direction, platform geometry and pile soil interaction. Besides, authors have produced other safety indicative ratios such as Structural Redundancy, Damaged Strength Ratio and Residual Strength Ratio to better describe the reliability of a platform other than Reserve Strength Ratio.

Oil and Gas Industry especially in Malaysia, needed and eligible for this reliability study since the almost all of the offshore platforms are jackets since the offshore operation in Malaysian waters is in the shallow water region. Pushover method can better describe the safety of a jacket platform by analyzing the safety indicative ratios produced. Sensitivity study on the parameters affecting the Reserve Strength Ratio will help scholar and operators identify and focus on the significant parameters that brings significant changes to the safety of a jacket platform.

II. PUSHOVER ANALYSIS

Pushover analysis is widely used in calculating the ultimate capacity as well as demonstrating the global instability of jacket platform [9]. Pushover analysis is a method to evaluate and provide estimation on the demands imposed on the structures and elements which is then comparing the estimation with the existing capacity to assess the acceptability of the design for reliability.

The processes is to first represent the structure in a two or three dimensional analytical model that take account for all important linear and non-linear response characteristic, then apply wave lateral loads in predetermined patterns that represent approximately the relative inertia forces generated at locations of substantial masses, and push the structure under these load patterns to specific target displacement levels [10].

Within any step, the program further selects a load sub-step size, by determining when the next stiffness change (event) occurs and ending the sub-step at the event. The structure stiffness is then modified and the analysis is performed on the next step until the entire load is being applied [11]. The internal forces and deformation computed at the target displacement levels are estimates of the strength and deformation demands, which need to be compared to available capacities [10]. Figure 1 below shows that the environmental load is being applied onto the jacket platform until it collapsed.

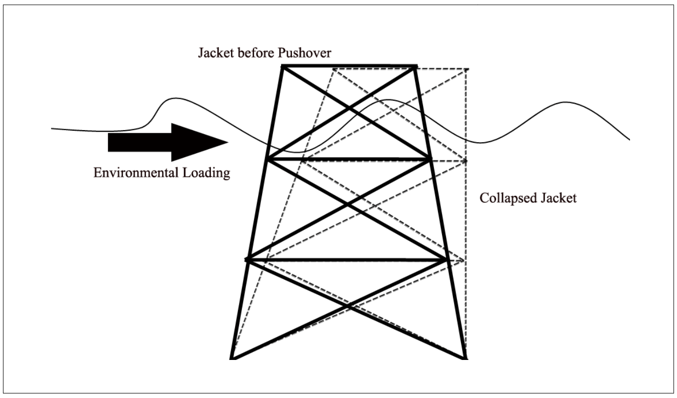

Fig. 1. Pushover Analysis by increasing the load factor of environmental loading until the structure collapses.

Some of the concerns about pushover analysis revolve around the load patterns, how far to push, and what is being evaluated [10]. The load is applied to the structure incrementally while the nodal displacements and element forces are calculated for each loads steps and the stiffness matrix is updated [12]. Since, the displacement corresponding to the collapse limit is somehow different for difference platform, [9] Commercial software's pushover analysis introduces plasticity when the stress in a member reaches the yield stress. With plasticity in the pushover analysis, the stiffness of the structure will be reduced and additional loads due to continuing load increments will be redistributed to the adjacent member of the ones which already gone plastic. This process will continue until the structure as a whole is collapsed [12].

In order to determine the ultimate strength of the platform requires information not only on the "as-built" and "present" characteristics of the platform but also knowledge of many interacting parameters including platform configuration, foundation characteristics and the excitation forces on the platform [13]. Hence the analysis will be done based on the updated model files of jacket platforms and also the soil data.

Ultimate capacity of platform can be determined using non linear push over analysis in which all the factored gravity loads, D are applied first and then the un-factored environmental loads, E till the platform collapses. Resistance of collapse is represented by Equation 1 that provided the push over strength of the member [14].

$$R_{ult} = \lambda_{ult} E \quad (1)$$

Where R_{ult} = Ultimate resistance of platform; and λ_{ult} = Factor which is increased until collapse [14].

III. Safety Ratios

Reserve Strength Ratio (RSR) is a measure of structure's ability to withstand loads in excess of those determined from platform's design and this can be obtained using the ultimate strength of the platform through pushover analysis. This reserve strength can be used to maintain the platform in service beyond their intended service life. Knowledge from the analysis can be used to determine the criticality of components within the structural system and used to prioritize the inspection and repair schemes [8]. RSR is the ratio of collapse base shear to the 100 year return period design base shear as shown in Equation 2.

$$RSR = \frac{BS_{collapse}}{BS_{100}} \quad (2)$$

Structural Redundancy (SR) is a measurement of thecollapse base shear of the structure to the base shear at the first member failure as shown in Equation 3. SR assesses theredundancy in the resistance of the structure after the failure of first member during the pushover analysis. If a structure has a SR=1.0, this indicated that the structure fails as the first member fails. If a structure has SR=1.38, this indicates that the structure fails at load level 38% greater than load level at first member failure [15]. Hence, a higher SR indicates that a structure has higher redundancy in resistance even after first member failure.

$$SR = \frac{BS_{collapse}}{BS_{first\ member\ failure}} \quad (3)$$

Damaged Strength Ratio (DSR)is the ratio of the load level at the collapse of the structure initially in a damaged condition to the 100 year return period design base shear as shown in Equation 4. The damaged structure is in condition where one member has failed or been severely damaged [15]. DSR is similar to RSR; however DSR is essential to be compared to RSR to observe the impact of the damaged member to the reliability of entire platform.

$$DSR = \frac{BS_{danaged}}{BS_{100}} \quad (4)$$

Residual Strength Factor(RIF) is an indication ratio of total reduction of capacity due to the effect of the removed member as shown in Equation 5. RIF can be obtained as a ratio of base shear of structure with *i*numbers of damaged members to the base shear with *i-1* numbers of damaged members [15]. If number of *i* is 1, $BS_{damaged_{i-1}}$would be same as$BS_{collapse}$.

$$RIF = \frac{BS_{damaged_i}}{BS_{damaged_{i-1}}} \quad (5)$$

IV. METHODOLOGY

This paper discuss the methodology of pushover analysis to obtain the RSR, SR, DSR, and RIF value as an indicator to the reliability of a jacket platform in Malaysian waters. Sensitivity study is also conducted to observe impact of different parameters to the safety ratios.

Pushover analysis consists of three main parts which is data preparations, structural modeling and progressive collapse analysis. Sensitivity analysis is conducted to identify the parameters that bring significant impact to the structural integrity of the platform.

Authors aim to study the effect of Pile Soil Interaction (PSI), geometry or orientation of the platform, different metocean loading at different directions, and all previously combined conditions to the RSR value. Authors will discuss and assess each combinations of pushover analysis and determine the most suitable one. Then, authors will proceed to produce the other safety ratios such as SR, DSR, and RIF based on the most suitable and critical condition for pushover analysis of a jacket platform.

Pushover Analysis

Platforms model file are presented in the form of model files as shown in Fig. 2. The platform model that was used for pushover analysis is the real existing platform that has been installed and the model file was updated so that the model file represents the real existing platform as close as possible. The platform model file have been updated using the information gained from structural drawings, underwater report, anomalies report, pile driving record, soil and foundation report and metocean data [16]. Other than the structural properties of the jacket platform, the pile soil interaction (PSI) behaviour is modeled using non linear spring elements so that can be considered during the collapse mechanism in the pushover analysis to provide an analysis that is as close as possible to the real existing jacket platform [17]. The metocean data incorporated into the program to generate environmental loads to the structures. The updated and availablemetocean data of sample platform 'A' is shown in Table I and Table II.

TABLE I. 100-YEAR STORM CONDITION WAVE PROPERTIES FOR PLATFORM 'A' AT DIFFERENT DIRECTIONS.

100-Year Return Period/ Storm Condition for Wave					
Direction	**H_s (m)**	**T_z (s)**	**T_p (s)**	**H_{max} (m)**	**T_{ass}(s)**
N (0°)	6.3	8.3	11.7	11.7	10.9
NE (45°)	6.3	8.3	11.7	11.7	10.9
E (90°)	4.7	7.5	10.6	8.7	9.8
SE (135°)	3.4	7.4	10.4	6.3	9.7
S (180°)	3.4	7.4	10.4	6.3	9.7
SW (225°)	4.7	7.5	10.6	8.7	9.8
W (270°)	5.5	7.9	11.1	10.2	10.3
NW (315°)	6.3	8.3	11.7	11.7	10.9

Pushover analysis mentioned wave loading as the environmental loading being increased until the structure collapsed [9]. The dominant loading exerted on the offshore platform consist of wave and current loading [15]. Hence, it is essential to have the metocean data from all direction. However, situation where lacking directional metocean data for example platform 'A' , compromises had to be made as such only different wave properties is incorporated into the model as 8 different directions, and current and wind is incorporated as the same for 8 different directions. The metocean data used for analysis is 100-year return period as in Table I and Table II; to generate enough loading to make the structure collapsed [17].

TABLE II. 100-YEAR STORM CONDITION WIND AND CURRENT PROPERTIES FOR PLATFORM 'A'

100-Year Return Period/ Storm Condition for Wind & Current				
Wind Speed (m/s)		Current Velocity		
1-hour mean	20	Height Above Seabed		(m/s)
10-min mean	22	Surface	1.0*D	1.20
1-min mean	24	Mid Depth	0.5*D	0.95
3-sec gust	26	Near Seabed	0.01*D	0.55

Fig. 2. The jacket model of platform 'A'

The platform model file as shown in Fig. 2 is performed static linear analysis to assess the platform model against the 100-year storm condition as a checking whether the platform model is valid. The platforms are designed using 100-year return period metocean data as per mentioned in API code. Hence, if the platform failed the static linear analysis, the platform model has error or the platform itself has deteriorated to a level that it cannot sustain the 100-year storm condition which is the design load baseline. Once the platform passed the static linear analysis,this means that there is no component failure so that the pushover analysis can be performed to assess the system failure of the platform.Pushover analysis will be conducted in the few cases with different conditions as show in Table III.

TABLE III. PUSHOVER ANALYSIS SENSITIVITY STUDY.

	PUSHOVER ANALYSIS	Case			
	Conditions	A	B	C	D
1	Pile Soil Interaction (PSI)	X			X
2	SameMetocean at all directions	X	X		
3	Different Metocean at each directions			X	X
4	8 Different directions	X	X	X	X

Pushover analysis will be conducted on jacket platform 'A' for 4 cases namely Case A, Case B, Case C and Case D which will be studied extensively as shown in Table III. Both Case A and Case is to be compared to each other to study the effect of PSI on the value of RSR by including PSI consideration in the pushover analysis for Case A and excluding PSI for Case B. Besides the effect of PSI, Case B has the purpose of studying the geometry effect of the jacket platform by excluding the PSI effect in the analysis, and using the same metocean loading on all 8 directions. This ensures that other effects such as PSI and different metocean loading is ignored to study the resistance of the jacket platform 'A' itself based on the geometry. For Case A and Case B, metocean loading with wave height = 11.70m and wave period = 10.9s for all 8 directions is used for analysis. Case C is to study the effect of omni-direction metocean loading which is different at each direction as shown in Table I. Real sea condition will not be having similar metocean from all direction like in Case A and Case B, but the on-site metocean reading is shown in Table I which will be used for Case C and Case D. However, the current and wind loading for all 4 cases studied are based on one single value as shown in Table II. This compromise has to be made due to lacking of data.

Pushover Analysis is carried out separately for eight selected loading direction for Jacket 'A' namely; N (0°), NE (45°), E (90°), SE (135°), S (180°), SW (225°), W (270°), and NW (315°) as shown in Fig.4. The self weight of the jacket platforms, buoyancy, installed equipments, live load are applied on the platform in the first phase of the pushover analysis with load factor of 1.0 [15, 16]. The second phase of the pushover analysis is applying the environmental load on the platform with increasing load factor until the platform collapsed. It should be noted that the wave theory used for analysis is Stoke's fifth order wave theory, wind drag force is in accordance to API RP 2A WSD and current's inertia and drag load is calculated using Morrison's equation [17].

There are two main convergence criteria in for the pushover analysis using commercial software's progressive collapse analysis module [12, 17]:

1. Number of member sub-segment; members with plastic material properties are divided into 1-8 sub-segments along the member length.
2. Global stiffness iterations and convergence; a beam column solution is performed for each plastic member using the cross section sub-element details for any load increment. The global stiffness iteration is performed including any effects of connection flexibility and nonlinear pile-soil foundation effects. The software will determine the deflected shape of the structure and compare to the displacements of the previous global stiffness iteration. The stiffness iterations are repeated until the displacements and rotations meet the displacement and rotation convergence tolerances or the maximum number of global stiffness iterations per load increment is 20 and the default displacement and rotation tolerances are 0.01 inch or 0.01 cm and 0.001 radians.

As shown in Equation 2, the ultimate capacity (collapse base shear) and design base shear loading on the jacket with respect to 100 year return period metocean loading (BS_{100}) can be used to find RSR. From the analysis, design base shear can be identify when the environmental load factor = 1.0, while collapse base shear is the maximum base shear upon collapse as shown in Fig.3.

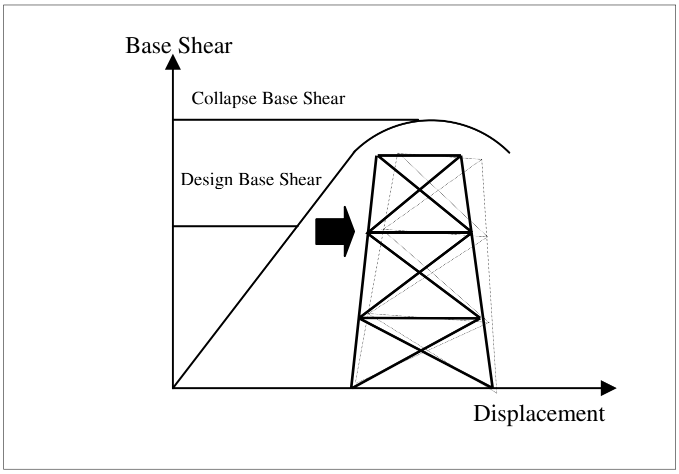

Fig. 3. Definition of Collapse Base Shear and Design Base Shear

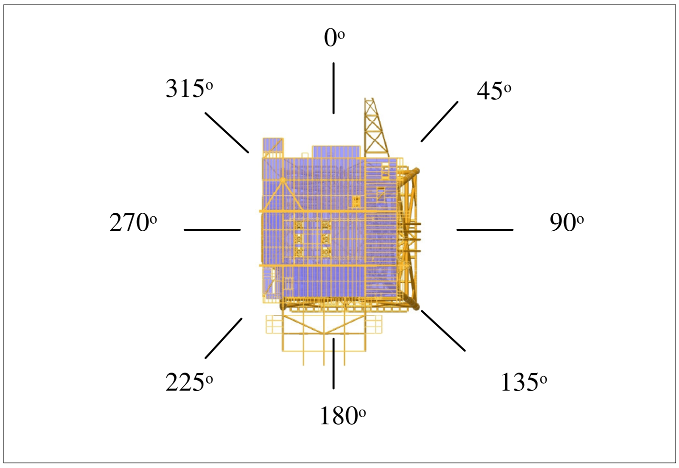

Fig. 4. The Eight (8) different orientations/directions of Jacket 'A'

Upon the completion of Pushover Analysis for all 4 cases, authors proceed to produce the safety ratios namely RSR, SR, DSR and RIF accordingly. The safety ratios will be discussed its significance and contribution in reliability of the jacket platform. For safety ratio such as RSR, the higher than value of RSR indicates the safer the structure is since there is much more reserved strength, hence the lowest RSR isthe most critical one, provided that the analysis is conducted based on the assumption closest to real life condition.

V. RESULT & DISCUSSION

TABLE IV. PUSHOVER ANALYSIS CASE A

Direction	Base Shear 100 Year Metocean (MN)	Collapse Base Shear (MN)	Reserve Strength Ratio, RSR
N (0°)	9.617	33.977	3.533
NE (45°)	9.355	37.979	4.060
E (90°)	9.730	31.709	3.259
SE (135°)	9.187	35.385	3.852
S (180°)	9.431	29.901	3.171
SW (225°)	9.235	24.010	2.600
W (270°)	9.810	20.894	**2.130**
NW (315°)	9.324	24.892	2.670

TABLE V. PUSHOVER ANALYSIS CASE B

Direction	Base Shear 100 Year Metocean (MN)	Collapse Base Shear (MN)	Reserve Strength Ratio, RSR
N (0°)	9.618	31.445	3.269
NE (45°)	9.357	36.759	3.928
E (90°)	9.731	40.968	4.210
SE (135°)	9.191	35.846	3.900
S (180°)	9.432	34.624	3.671
SW (225°)	9.237	28.364	3.071
W (270°)	9.813	23.487	**2.393**
NW (315°)	9.326	29.404	3.153

TABLE VI. PUSHOVER ANALYSIS CASE C

Direction	Base Shear 100 Year Metocean (MN)	Collapse Base Shear (MN)	Reserve Strength Ratio, RSR
N (0°)	9.618	31.445	3.269
NE (45°)	9.357	36.759	3.928
E (90°)	6.754	45.276	6.703
SE (135°)	4.699	31.403	6.684
S (180°)	4.645	30.952	6.663
SW (225°)	6.490	27.045	4.167
W (270°)	8.304	23.346	**2.811**
NW (315°)	9.326	29.404	3.153

TABLE VII. PUSHOVER ANALYSIS CASE D

Direction	Base Shear 100 Year Metocean (MN)	Collapse Base Shear (MN)	Reserve Strength Ratio, RSR
N (0°)	9.616	33.977	3.533
NE (45°)	9.355	37.979	4.060
E (90°)	6.752	31.552	4.673
SE (135°)	4.697	35.014	7.455
S (180°)	4.644	31.084	6.693
SW (225°)	6.488	24.914	3.840
W (270°)	8.302	21.409	**2.579**
NW (315°)	9.324	24.893	2.670

Table IV shows the pushover analysis results for case A which is considering PSI and using the same maximum metocean loading at all 8 directions. Table V shows the results for case B which ignore the PSI and the rest of the conditions is similar to case A. The RSR values from case B are observed to be slightly higher than RSR values of case A. For Table VI, case C has RSR value which is much higher if compared to case A and case B. Finally for Table VII which is case D which included the PSI effect and the other conditions is similar to case C.

It is observed that in the case of comparing case A and case B, the RSR value generally is much lower if the PSI is included. This is because if the PSI is not considered, the software will assume the end of the platform leg is fixed end connection which of course will generate higher resistance compared to pile soil behaviour which taken into consideration the residual soil strength. The most critical RSR for case A is at W (270°) direction.

For case B, same metocean loading is exerted on all 8 directions to examine the resistance of the platform based on orientation alone. The RSR vale is ranging from 2.393 to 4.210 which suggest that no obvious evidence that the end on face is more critical than diagonal face of the platform. The platform collapsed due to the continuous member failure in the system upon the increasing environmental loading. However, it is observed that end-on and broadside of platform which is N (0°), E (90°), S (180°), and W (270°) experienced slightly higher design base year compared to the diagonal side of the platform.

For case C, different metocean loading is exerted on 8 different directions as in Table I and excluding PSI. Case C shows that the different metocean loading brings significant difference to the RSR value. The lower wave height at E (90°), SE (135°), S (180°) and SW (225°) direction results in much higher RSR compared to other directions. This is mainly due to the lower design base shear as the result of lower wave height. This shows that wave height is significant in metocean loading and the reliability of the platform.

For case D, PSI and different metocean loading at each direction is taken into consideration for the pushover analysis. It is noticeable that RSR values for case D is slightly different from case C because of the effect of PSI. Case D is the best condition for pushover analysis as the different metocean loading at each direction and PSI is used for analysis. Although the RSR values of case D is not the most critical one as in the lowest, but case D is closest estimate to the real existing platform's strength because relevant metocean value and PSI were incorporated in Case D. Hence, safety ratios such as SR, DSR and RIF will be based on case D.

Table VIII shows the Structural Redundancy (SR) of jacket platform 'A' for 8 directions. All the directions have redundancy in terms of capacity even after the failure of the first member during pushover.

TABLE VIII. STRUCTURAL REDUNDANCY (SR)

Direction	Base Shear First Member Failure (MN)	Collapse Base Shear (MN)	SR
N (0°)	20.288	33.977	1.675
NE (45°)	33.584	37.979	1.131
E (90°)	30.747	31.552	1.026
SE (135°)	29.331	35.014	1.194
S (180°)	21.932	31.084	1.417
SW (225°)	22.969	24.914	1.085
W (270°)	19.919	21.409	1.075
NW (315°)	23.773	24.893	1.047

Table IX shows the Damaged Strength Ratio (DSR) of jacket platform 'A' for 8 directions. The first member failure is identified during the pushover analysis for case D and the respective first failed member was removed from the jacket model file to imitate the condition of a damaged platform. DSR represents the Reserve Strength Ratio of a damaged platform. As shown in Table IX, the DSR value is concurrent with RSR values in Table VII. For directionE (90°),SW (225°), and W (270°), the capacity of the platform plummeted due to the removal of member 102-179(E) and101-176(SW and W) and this shows that those particular members are very critical members which is not susceptible to failure. For all the other directions, member A045-501X is removed.

TABLE IX. DAMAGED STRENGTH RATIO (DSR)

Direction	Base Shear 100 Year Metocean (MN)	Base Shear Damaged (MN)	DSR
N (0°)	9.598	31.002	3.230
NE (45°)	9.335	20.926	2.242
E (90°)	6.752	0.094	0.014
SE (135°)	4.687	25.994	5.546
S (180°)	4.634	31.985	6.903
SW (225°)	6.488	1.178	0.182
W (270°)	8.302	1.178	0.142
NW (315°)	9.305	29.757	3.198

Table X shows the RIF which is the capacity reduction ratio due to first member failure of jacket platform 'A' at 8 directions. Direction E (90°),SW (225°), and W (270°) show significant reduction in terms of capacity, similar to results in Table IX, while other directions shows RIF values around 1.0 which means there is not much reduction due to the first damaged member.

TABLE X. RESIDUAL STRENGTH FACTOR (RIF)

Direction	Collapse Base Shear (MN)	Base Shear Damaged (MN)	RIF
N (0°)	33.977	31.002	0.912
NE (45°)	37.979	20.926	0.551
E (90°)	31.552	0.094	0.003
SE (135°)	35.014	25.994	0.742
S (180°)	31.084	31.985	1.029
SW (225°)	24.914	1.178	0.047
W (270°)	21.409	1.178	0.055
NW (315°)	24.893	29.757	1.195

CONCLUSION

The following conclusion can be made using the results provided from above:

1. Pushover analysis can be used to assess the reliability of jacket platform by producing safety ratios.
2. Different metocean loading at different direction and Pile Soil Interaction is essential in pushover analysis.
3. Pushover analysis and DSR helps identify the critical members which will cause reduction in jacket platform's capacity if damaged or missing.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support and project data given by PETRONAS and UniversitiTeknologi PETRONAS for the facilities and staff support.

REFERENCES

[1] N.W. Nichols; T.K. Goh, and H. Bahar, "Managing Structural Integrity for Aging Platform", Proceedings, SPE Asia Pacific Oil and Gas Conference and Exhibition, Adelaide, Australia, No SPE101000, September 2006.
[2] S.A. Kheiri and M.R. Bahaari, "Evaluation of Ultimate Strength of Jacket Type Structures under Marine Loading", Proceedings, 7th International Conference on Coasts, Ports and Marine Structures, November 2006.
[3] M. Fadly N. A., "Sensitivity Study of Environmental Load to Reliability Index for Malaysian Region", Master Degree Thesis, Universiti Teknologi Petronas, Malaysia, 2011.
[4] V.J. Kurian, Z. Nizamani, and M.S. Liew, "Modelling for Uncertainties in Resistance for Jacket Platforms in Malaysia", Research Journal of Applied Sciences, Engineering, and Technology. vol. 5, pp. 750-759, January 2013.
[5] N.Shabakhty, "Durable Reliability of Jack-up Platforms – The impact of fatigue, fracture and effect of extreme environmental loads on the structural reliability", PhD Thesis, T. U. Delft, Netherlands, 2004.
[6] J. Rajasankar, N.R. Iyer, and T.V.S.R. Appa Rao, "Structural Integrity Assessment of Offshore Tubular Joints based on Reliability Analysis", Elsevier, International Journal of Fatigue, vol. 25, pp. 609-619, July 2003.
[7] T. Onoufriou and V.J. Forbes, "Developments in Structural System Reliability Assessments of Fixed Steel Offshore Platforms", Elsevier, Reliability Engineering System Safety, vol. 71, pp. 189-199, February 2001.
[8] S.P. Narayanan and M.K.B.M.Akram, "Structural Integrity Management for Fixed Offshore Platforms in Malaysia", World Academy of Science, Engineering and Technology, vol. 58, pp. 19-26, 2009
[9] A.A. Golashani, V. Bagheri, H. Ebrahimian, and T. Holmas, "Incremental Wave Analysis and Its Application to Performance-based Assesment of Jacket Platform", Journal of Constructional Steel Research, vol. 67, pp. 1649-1657, October 2011.
[10] H. Krawinkler, "Pushover Analysis: Why, How, When, and When Not to Use It", Proceedings, 1996 Convention, Structural Engineers Association of California, October 1996.
[11] B. Asgarian and M. Lesani, "Pile-Soil-Structure Interaction in Pushover Analysis of Jacket Platforms Using Fiber Elements", Journal of Constructional Steel Research, vol. 65, pp.209-218, January 2009.
[12] SACS Software manual.
[13] C. Capanoglu and S. Coombs, "Requalification Process for Existing Platforms Implications of Newly Acquire Criteria on Mitigation", Proceedings, International Offshore and Polar Engineering Conference, Osaka, Japan, June 2009.
[14] V.J. Kurian, Z. Nizamani, M.S. Liew, and M.M.A. Wahab, "System Reliability for Jacket Platform Subjected to Wave and Current Loads", Proceedings, International Conference on Civil, Offshore & Environmental Engineering, Kuala Lumpur, Malaysia, June 2012.
[15] G.Ersdal, "Assessment of Existing Offshore Structures for Life Extension", Doctorial Thesis, Faculty of Science and Technology, Department of Mechanical and Structural Engineering and Material Science, University of Stavanger, October 2005.
[16] Group Technical Soulution (GTS), "Global Ultimate Strength Analysis for SBO Platform: SMJT-E", Report ID: RD-PLE-CSP-RBI-S309, 2011
[17] P.Pueksap-anan, "Sensitivity Analysis for RSR Offshore Steel Type Platforms", Master Degree Thesis, Asian Institute of Technology, School of Engineering and Technology, Thailand, August 2010.