Enhancement of Structural Reliability of Jacket Platforms in Malaysian Waters for Life Extension

By

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16006

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Montasir Osman Ahmed Ali)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(KOK HOY SENG)

ABSTRACT

Most of the jacket platforms that belongs to PETRONAS Carigali Sdn Bhd have been operated more than their service life for Enhancement of Oil Recovery (EOR). However, it is uncertain to claim the platforms are safe for life extension. Hence, enhancement of structural reliability becomes a necessity to justify the platform is safe throughout the EOR period. In this paper, the effect of local joint flexibility on enhancement of structural reliability of offshore jacket structure in Malaysia waters will be studied. Rigid joint assumptions made during software modelling of jacket structures, had been practiced for past decades. While, standards such as API RP2A-WSD only applies local joint flexibility to the fatigue life analysis. However, past researches show that tubular joints of offshore structure in reality are not fully rigid but possesses flexibilities. In this project, pushover analysis will be perform on the F9JT-A platform model using SACS 5.3 software .100 years return periods of storm were considered as environmental loading and pile soil interaction were included in the pushover analysis for intact and structure with local joint flexibilities(LJF). LJF (Fessler and Buitrago LJF methods) were introduced to all joints of the jacket structure, to determine the effects of LJF to the reserve strength ratio (RSR). The Buitrago method shows better results compare to Fessler method in improvement of RSR. Buitrago method shows a maximum of 21.2% improvement in RSR on 90^{o} loading direction, while Fessler show a maximum improvement of 6.43% in RSR on 270b^{o} loading direction when compared with intact RSR. While for structural reliability analysis, reliability index and probability of failure were obtained through FORM and MCS method, results from Buitrago method shows better result compare to Fessler method with a maximum improvement of 8.817% for reliability index and a maximum reduction of 98.98% for probability of failure when compared with intact structure. While the Fessler method shows a maximum improvement of 3.86% in reliability index and a maximum reduction of 79.67% in probability of failure when compared with the intact structure.

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ABBREVIATIONS AND NOMENCLATURES

BF Buitrago local joint flexibility

D Outer Chord Diameter

E Young’s modulus of elasticity

FORM First-Order Reliability Method

I The moment of inertia, A is the Area of short-flex element

JF Fessler local joint flexibility

L Flex-element length

LJF_{AX} Local joint flexibility of axial

LJF_{OPB} Local joint flexibility of Out-of plane bending moment equation

LJF_{IPB} Local joint of In-plane bending moment equation

(LJF_m) In-plane or Out of plane bending local flexibility

(LJF_p) Axial loading local joint flexibility

MCS Monte-Carlo Stimulation

RSR Reserve Strength Ratio

SACS Structural Analysis Computer System

Chapter 1: INTRODUCTION

1.1 Background of study

More than 60% of the platforms from PETRONAS Carigali Sdn Bhd (PCSB) had been operating for more than 20 years while some have exceeded 30 years compare to their initial designed service life of 20 to 25 years. The extension of service life demand for these operating platforms however had been increasing due to enhanced of oil recovery. Because of this, upgrading, modification and work-over demand will certainly increase the loads subjected to the jacket structure where the platform was not initially designed for. Moreover, the increase in environmental met-ocean loading, seismic loading, shallow gas and other challenges will also significantly affect the jacket structure throughout the years of its service life (Nichols, 2006).

Structural reliability analysis becomes necessary to ensure the structure is safe. The probability of a system perform its purpose in a specified period without failing is known as reliability. Choi et al. (2007) stated the structural reliability study; focus on the calculation and prediction of the probability of limit state violations at any stage of the structure service life. The probabilistic approach is based on the theoretical foundation of Probability Distribution Factor (PDF) information. In addition, the uses of random variables, process and field are introduced to represent uncertainty. To further enhance the structural reliability, local joint flexibilities is one of the approach.

The reliability of the platform for service life extension can be determined by assessing the reliability index and probability of failure which is through Reserve Strength Ratio (RSR). RSR is determined by dividing the ultimate strength to the design strength. The ultimate strength can be determined through pushover analysis. The pushover analysis is used as the capacity of the jacket structure depends significantly in non-linear range of deformation of the behaviour of structure members and the foundation interaction with soil.

As significant number of platforms in Malaysia are extending their service life for continuous production, this research would be a valuable for PETRONAS, our national oil company.

1.2 Problem statement

The existing jacket structure are safe regard to overloading due to wind, current and wave loading, provided that the load is not significantly different from the load the structure was initially designed for (Ersdal, 2005). However when the structure is used beyond its service life, it would be uncertain to claim the structure is still safe for the coming years of operations.

Offshore jacket platforms possess some flexibilities in the joints in reality and there were a lot researches have been conducted on the effect of local joint flexibilities on the overall structure behaviour, and it was included recently in fatigue analysis. However, this local joint flexibilities effect was not included in most the offshore structures' finite element analysis such as in-place analysis and nonlinear pushover analysis.

Hence, enhancement of structural reliability of the jacket platform by considering the effect of local joint flexibilities to determine the actual strength of the jacket platform in Malaysian waters is necessary to requalify the strength of jacket platform.

1.3 Objectives

The main objective of this project is to analyse the factors that contribute to the enhancement of the structural reliability of jacket platforms in Malaysian waters for life extension.

This main objective can be subdivided into few sub-objectives as follows:

i) To determine the Reserve Strength Ratio (RSR) of the intact F9JT-A platform model using SACS 5.3 software.

ii) To determine the effect of the local joint flexibilities to the RSR improvement on the F9JT-A jacket structure using SACS 5.3.

iii) To determine the effect of joint flexibility on structural reliability of F9JT-A platform through First-Order Reliability Method (FORM) and Monte-Carlo Stimulation (MCS) methods using MATLAB.

1.4 Scope of study

The scope of this project is limited to the following constrains:

i) F9JT-A jacket platform provided by PETRONAS Carigali will be used in this project.

ii) The static non-linear pushover analysis using SACS 5.3 is used in this project.

iii) Deterministic value of wind, wave and current loading as environmental loading will be consider in this project to evaluate response of the jacket platform.

iv) Only both Fessler and Buitrago local joint flexibility methods will be include during pushover analysis for structure with local joint flexibilities.

v) Structural Reliability Analysis will be performed using FORM and Monte Carlo Stimulation (MCS) methods through MATLAB.

Chapter 2: LITERATURE REVIEW

This chapter will introduce the concept of structural reliability assessment, pushover analysis, ultimate strength assessment, reserve strength ratio (RSR), enhancement of structural reliability, First Order Reliability Method (FORM) and Monte Carlo stimulation (MCS).

2.1 Structural Reliability Assessment

The capability of the offshore structure to meet its purpose under any condition is known as structural reliability. Determination of whether the limit-state of structure is exceeded is how the reliability analysis evaluates the probability of failure of a structure. The confidence interval of structural response and probability distribution function are very important for reliability analysis as mention by Choi S.K et al. (2007) in their book.

The limit state, whereby the structure exceeded its specific limit and is unable to carry the load which is initially design for is considered as unreliable. There are two types of limits state, ultimate-limit states and serviceability limit-state. The ultimate limit-state is very unlikely to occur is caused by progressive collapse, plastic mechanism, fire, fracture, fatigue, deterioration and corrosion. As for the serviceability limit-state, is caused by leakage, local damage, excessive vibration and deflection which are not as critical as ultimate limit-state.

In term of structural system reliability assessment, pushover analysis has a huge role to assess the resistance capacity of the offshore structure. Onoufriou, and Forbes (2001) in their research focus on three main part of the jacket platform for pushover analysis besides the failure mechanism and application of loads, which include the superstructure, substructure and the foundation.

The reliability of the platform for extended usage can be determined by the reliability index and probability of failure of the platform structure, and this will determine whether the platform structure is suitable and reliable for extended usage.

2.2 Fixed Jacket Structure

Fixed jacket structure or offshore jacket platform is a structure that is totally made up of tubular steel frame with pile foundation that is located on shallow sea. While the structure members of the jacket consist of X, Y and K joints and members. Production facilities, living quarter and helideck are all included on the superstructure of the jacket platform. The purposes of jacket structure are to process the crude oil/gas from reservoir and pumped to shore through pipelines after process. The design of jacket structure depends on various requirements, which include fatigue and strength and it is design to have a typical service life of 10 to 25 years (Randall, 2010).

2.3 Pushover Analysis

Pushover analysis which has the same function as the non-linear analysis which is used to determine the Ultimate Strength of the jacket platform is carried out to determine whether it is safe for continuous usage of the existing jacket structure by determine the RSR of the structure.

Asgarian and Lesani (2007) mention that to determine the ultimate strength of the jacket structure, pushover analysis is the most general method. Buckling, member failure due to yielding, joint failure and pile soil failure, are the important assessment for offshore platforms are all included in the pushover analysis. During the pushover analysis, loads are pushed to the jacket structure until the jacket collapsed or targeted displacement is achieved.

Onoufriou and Forbes (2001) found the capacity and response of the whole structure of jacket offshore platforms significantly rely on the deformation of structure member in the non-linear range in their research. Most critical member will be determined by pushover analysis. However, the effects of possible component strength variation result in different combination of elements and failure sequence will not be considered.

Non-linear pushover analysis assesses the non-elastic range of the structure in order to determine the weakest joint/point of the structure together with the failure mechanism of the structure. In the research of Krawinkler and Seneviratna (1998), the weakest point, which is hidden from the elastic analysis is shown by non-linear pushover analysis and at same time provides a more reliable result for the assessment of jacket structure.

According to krawinkler (1994), pushover analysis is used for evaluating the design's solution as this analysis does will not provide a good solution. However, pushover analysis will analyse and forecast the load and failure mechanism happens to the elements of the structure. Two and three dimensional model is analysed in the analysis, which will account for both linear and nonlinear response of the structure. The structure was pushed to a targeted displacement by applying lateral loads which represent the relative inertia forces that developed at location of substantial masses. While the deformation and internal strength calculated through the pushover analysis are then comparing to the available capacities.

Onoufriou and Forbes (2001) performed the pushover analysis by applying gravity load to the structure, followed by lateral loads which are applied incrementally to the structure until the structure eventually collapses. Beside material properties, joint failure is the main focuses in their analysis although there are many cases where failure of member will occur first before joint failure because the joint failure will affect the estimation of ultimate load and failure mechanism of the jacket structure.

During the pushover analysis, points were considered as hinges when they reached the bending strength in the application of lateral loads. The analysis will continue even it exceeded the targeted displacement, which will result in a base shear vs. displacement response curve. Non-linear curve component description is shown is Figure 2-1.

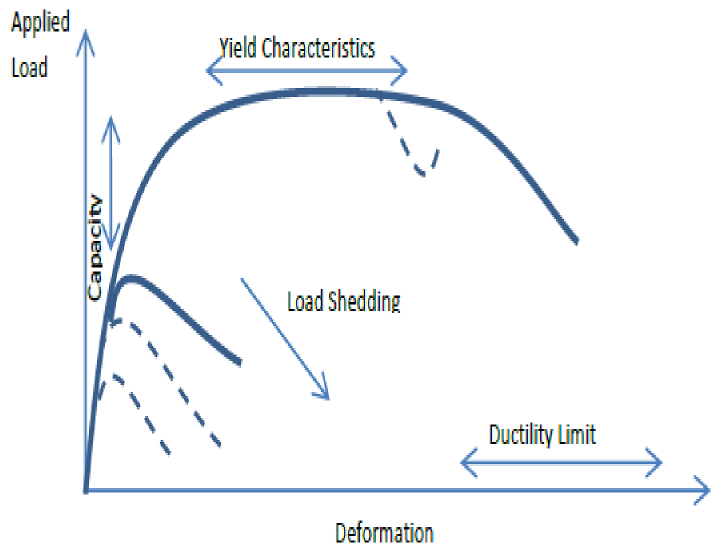

FIGURE 2-1 Non-linear curve component description (V.J. Kurian at el, 2013)

2.3.1 Advantages of pushover analysis:

Pushover analysis is a method that considered the redistribution of internal forces, this is vital when the structure unable to resist the internal forces in the elastic range. Pushover Analysis also evaluates more comprehensive and realistic compared to linear elastic analysis. Hence, when dynamic analysis or static linear elastic analysis unable to obtain targeted information on response characteristic from a structure, pushover analysis is used.

The response characteristic provided by pushover analysis according to krawinkler (1994) includes:

i) Deformation demand estimation of element that will deform inelastically to release the ground motion energy transmitted to the structure.
ii) The behaviour of structural system affected by the individual member strength deterioration.
iii) Strength discontinuities identification that will cause the dynamic characteristic to change in inelastic zone.
iv) Identification and focus on critical regions which have high deformation demand through detailing.

Pushover analysis will also check the load transfer across connection between ductile materials with realistic forces. Most importantly, it will cover all the elements from the structure, which include structural or non-structural elements which will cause distribution of significant loads.

2.4 The Ultimate Strength Assessment of Offshore Structures

WestLake et al. (2006) in their paper, state that non-linear finite element analysis, also known as collapse analysis or pushover analysis will be used for the ultimate strength assessment of offshore structures. This analysis will assess the capacity of the entire system of the structure.

WestLake et al. (2006) in their research, found that each directional environmental loading, will cause the structure to have different RSR. While the environmental loading direction which causes the lowest RSR to the structure will be the main focus.

The plastic deformation of piles, members and joints are allow in this ultimate strength assessment, and the components of the structure are allow to undertake load above the yield strength. In addition, the loads applied to the structure are all redistributed to all the structure members until the structure eventually collapses.

2.5 Reserve Strength Ratio (RSR)

According to Titus and Banon (1988) (Bolt et al, 1996) RSR is the term used for offshore platform ultimate strength measurement. It is the measurement of the ability of the structure to withstand overloading as compared to the initial designed load of the offshore platform. RSR value obtained through the pushover analysis will determine whether the jacket platform is reliable for the continuous usage for the industry. However, the RSR is greatly affected by the load combination and the environmental loading direction subjected to the jacket structure.

2.6 Enhancement of Structural Reliability

In current practice, the tubular joints/connections are all assumed to be fully rigid during analysis for offshore jacket platforms. However, their true behaviour is essentially flexible. (Nichol et al. 2006)(Masoud et al, 2009). This is due to lack of knowledge on how the actual behaviour of tubular joints can be represented in frame test and large scale component.

Present-day practice with no flexibility on tubular joint, will give inaccurate joint response of the structure in the analysis result. Hence, joints should be represented with finite linear elastic flexibility where it represent the accurate way of joint behave in practice, which is suggested by Structural engineering mechanics.

There are extensive data showing that all the tubular joints are flexible, that differ depends on geometry load case and joint types. Masoud et al (2009) state the flexibilities of the connection should be considered to obtain accurate stiffness and strength of the platform as connections are not perfectly rigid. Masoud et al (2009) also obtained a significant result in the research by comparing a fully rigid structure and a structure which includes flexibilities on connection. Besides, Masoud et al (2009) also found that effect of flexibilities of joint become apparent in non-linear analysis where the structure undergo plastic region.

Local joint flexibility (LJF) is now introduced to the fatigue analysis in a very reliable and cost-effective manner (MSL, 2002) (Nichol et al (2006). Local joint flexibilities had been implemented by introducing short “flex-element” at the end of the brace which connect to the surface of the chord. To verify this method, a T-joint was created using SACS software which has the same geometry as the test specimen was selected from a database that contain data of full-scale failure test on tubular joints. Analysis was carried out for both with and without flex-element T-joint. The result from the test shows the predicted of T-joint with flex-element’s deformation is close to the test result from database, while the rigid joint model’s result is not matching at all. Research had been done on a platform by MSL (2002), where a more accurate fatigue life prediction was obtained that had a similar result with the result obtained from under water inspection when the flex-element was introduced to the jacket structure finite element model.

2.7 First-Order Reliability Method (FORM)

FORM is probabilistic method that is used to evaluate the reliability of a system. Sokheang (2014) in his research found that, the component probability of failure can be determined by FORM method. The determination of whether the limit state function is an uncorrelated normal variables, linear function or linear first order approximation with equivalent normal variables represent the non-linear limit state function are evaluated using FORM method.

2.8 Monte Carlo Stimulation (MSC) Method

The Monte Carlo Stimulation method is a simple random sampling method that is use to determine uncertainty. The approximate probability of an event can be determine using this method as MSC contain statistical analysis of trial output, variable reduction techniques and digital generation of random variables and function (Choi et al ,2007). The structure probabilistic characteristic response can be determined by stimulation through generated sampling set for the analysis of structural reliability according to probability density function.

2.9 Critical Analysis

This section discuss the analysed critical analysis based on past research papers on implementing joint flexibilities to the offshore jacket platforms and the gaps between this project and past researches, are shown in table 2-1 and table 2-2.

TABLE 2-1 Critical analysis on past research papers

	Authors	
	Onoufriou.T and Forbes. V.J (2001)	MSL Engineering Ltd (2002)
What they Studied	System Reliability Assessment of Fixed Jacket Platforms. They also study the various system effects (deterministic and probabilistic effects) and their relative contributions to the overall system reliability	The effects of local joint flexibility on the reliability of fatigue life estimation by comparing fatigue life predicted for rigid joint structure and flexible joint structure in the North Sea
Methods	Pushover Analysis under extreme Environmental Loading	Pushover Analysis using SACS, include Local joint flexibility (LJF), hydrodynamic loads
Remarks	Uncertainties on pushover prediction based on assumption made (foundation effects, joint failure, extreme loading and fatigue conditions)	A more accurate fatigue life prediction with a closer agreement results from underwater inspections

TABLE 2-2 Critical analysis on past researches and gap between this project.

	Authors		Gap
	Nichols et al (2006)	Masoud et al (2009)	
What they Studied	Study the fatigue analysis on the structure based on rigid and flexible joints	The effect of joint flexibility on overall behaviour of two jacket platforms, effect of joint flexibility on natural frequency of vibration of the structure and the process of plastic hinge formations	Enhancement of structural reliability of jacket platforms in Malaysia Waters
Methods	Pushover Analysis using SACS, Implement Local Joint Flexibility (Buitrago Method) on various joints and tested on the tubular joint prototype.	Nonlinear static and Dynamic analysis	Using SACS, to implement joint flexibility (JF and BF) to specific joints of the structure to determine the Reserve Strength of the jacket structure and on the same time determine the effects of joint flexibility to the RSR.
Remarks	The predicted fatigue life increased, and the result from the analysis is closer to the result of full scale test on the tubular joint.	Joints are not perfectly rigid, and the flexibility should be implemented to obtain accurate strength and stiffness of the platform. Recommend to take joint flexibility into account in design and analysis of	

		offshore structure. Flexible connections shows higher displacements and inter-storey drifts, lower base shear cause by low stiffness and strength of jacket structure. Overestimation of lateral capacity of structure if joint flexibility is not included.	

Chapter 3: METHODOLOGY AND PROGRESS

This chapter will describe method use in this project, from how information was sourced, the project carried out and plan.

F9JT-A Jacket Structure description

Kumang Cluster F9JT-A platform is a jacket platform, located in Sarawak in the South China sea, 200m away from the MLNG plant offshore Bintulu Sarawak. F9JT-A is typical unmanned four legged fixed jacket structure which operates in shallow water with water depth of 94.8m. There are total six decks at the topside of the structure, which consist of helideck, main deck, mezzanine deck, cellar deck, sub cellar deck and SNV access deck. (MMC Oil & Gas Engineering)

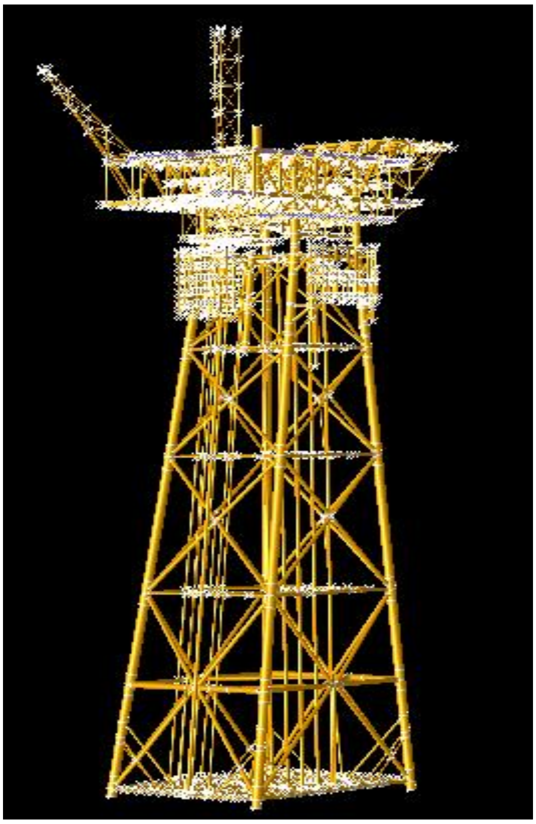

FIGURE 3-1 F9JT-A in SACS view

3.1 Methodology

Non-linear analysis can be used to determine the ultimate strength of the jacket structure, as it will consider the large deflection and plasticity of material in the analysis.

In this research, pushover analysis was chosen as the suitable analysis to determine the ultimate resistance capacity of the jacket structure. Non-linear Pushover analysis has been used for many years which include both onshore and offshore for researches to determine the structural behaviour especially in the failure mechanism and identify the weakest point of the structure in the inelastic range.

The pushover analysis was performed by subjecting the structure to lateral loads. These lateral loads were the environmental loads that include the wind, wave and current that will be applied to the jacket structure, as referring to Omni-directional loading from API-RP2A-WSD. For the structure used in this project, load will be applied from 8 directions which are the 0 degree, 45 degree, 90 degree, 135 degree, 180 degree, 225 degree, 270 degree, and 315 degree as shown in figure 3-2.

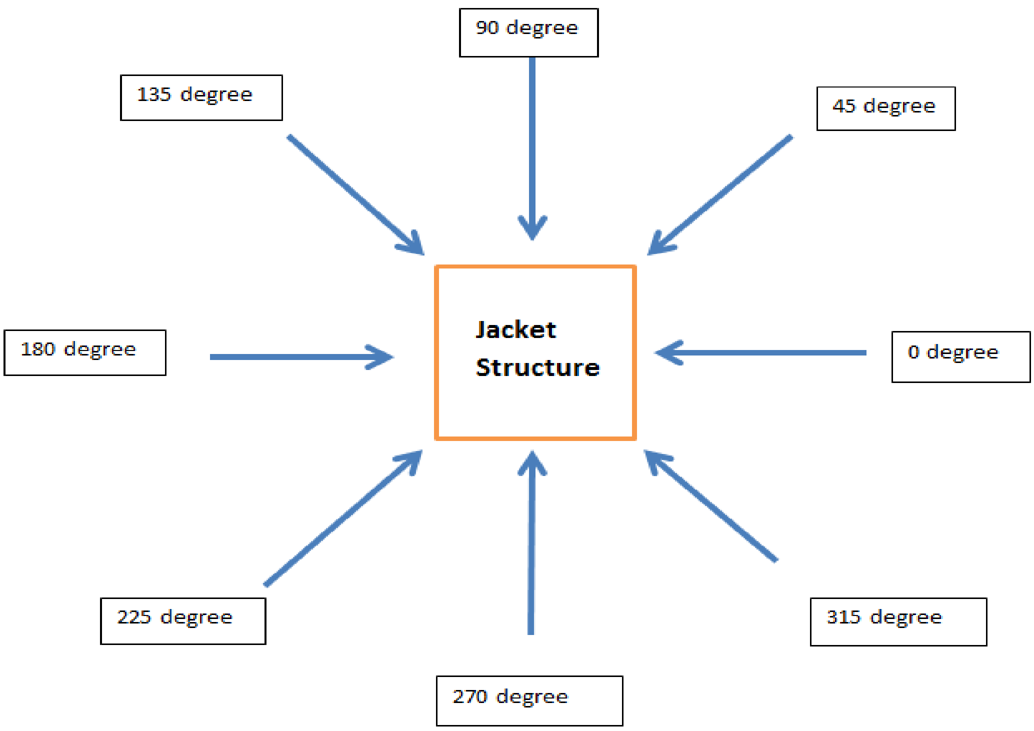

FIGURE 3-2 The Omni-directional lateral loads that are applied to the structure during Pushover analysis.

During the analysis, the chosen direction designed storm loads were applied to the structure and the lateral loads were factored incrementally until the structure collapse where the ultimate strength of the structure reached.

The reliability of the jacket structure can be represented by the Reserve Strength Ratio of the jacket structure via the pushover analysis by converting the jacket platform resistance capacity into the Reserve Strength Ratio.

The RSR defined by Titus and Banon(1988)(Bolt et al,1996) as:

$$\mathrm{RSR} = \frac{\text{Ultimate Platform Resistance}}{\text{Design Load}} \qquad (3.1)$$

Detailed steps are shown in the following to determine the Reserve Strength Ratio, implementing joint flexibilities to the jacket model using SACS 5.3 software.

i) F9JT-A platform model was obtained. Further modifying of the structure model was done when there is a necessity using the SACS 5.3 software.

ii) Load subjected to the jacket model were as according to the initial designed data. During load application process, the combination of live loads, dead loads and environmental loads were determined so as to find the combination of loads which give the most significant effect to the structure.

iii) The non-linear pushover analysis was done by applying the lateral loads from all the 8 directions using SACS 5.3.

iv) The RSR was determined using pushover analysis for the intact structure.

v) Implement local joint flexibility to the jacket platform model using JF and BF local joint flexibility options to the specific joints of the jacket model.

vi) Determine the RSR via pushover analysis for the structure with the flexibility introduced to the specific joint of the jacket structure.

vii) The results obtained will be compared

viii) Interpretation of results.

Implementation of local joint flexibility

Buitrago equations and Fessler equation method were used in this project. Both Fessler and Buitrago equation are the option provided by SACS software to implement the joint flexibility to the structure.

JF option that use Fessler equation is the equation originally used by SACS software on tubular joints to implement joint flexibility. The Fessler local joint flexibility equations provided by SACS Collapse Manual are as follow:

$$LJF_{AX} = \frac{1.95\gamma^{2.15}(1-\beta)^{1.3}\sin^{2.19}\emptyset}{ED} \tag{3.2}$$

$$LJF_{OPB} = \frac{85.5\gamma^{2.2}\exp(-3.85\beta)\sin^{2.16}\emptyset}{ED^3} \tag{3.3}$$

$$LJF_{IPB} = \frac{134\gamma^{1.73}\exp(-4.52\beta)\sin^{1.22}\emptyset}{ED^3} \tag{3.4}$$

$$\beta = \frac{\text{Brace diameter(d)}}{\text{Chord diameter(D)}} \tag{3.5}$$

$$\gamma = \frac{\text{Chord diameter(D)}}{2*\text{Chord thickness(T)}} \tag{3.6}$$

$$\emptyset = \text{Chord} - \text{brace interection angle}$$

Where:

LJF_{AX} is the local joint flexibility of axial

LJF_{OPB} is the local joint flexibility of Out-of plane bending moment equation

LJF_{IPB} is the local joint of In-plane bending moment equation.

While BF option (Buitrago Joint flexibility method), involved inserting a short flex-element at the end of the selected brace, the flex-element is connected with both brace and surface of the chord. In this project, SACS 5.3 software will automatically implement the method when the BF option is selected.

Buitrago local joint flexibility Equations (DNV-OS-J101 (2004)) are as follow:

$$I = \frac{L}{E(LJF_m)} \qquad (3.7)$$

$$A = \frac{L}{E(LJF_p)} \qquad (3.8)$$

$$LJF_p = \frac{f_{axial}}{ED} \qquad (3.9)$$

$$LJF_m \ (LJF_{IPB}) = \frac{f_{IPB}}{ED^3} \qquad (3.10)$$

$$LJF_m = \frac{f_{OPB}}{ED^3} \qquad (3.11)$$

Where:

I is the moment of inertia, A is the Area of short-flex element

L= flex-element length

(LJF_m)= In-plane or Out of plane bending local flexibility

(LJF_p)= Axial loading local joint flexibility

E=Young’s modulus of elasticity

D= Outer Chord Diameter

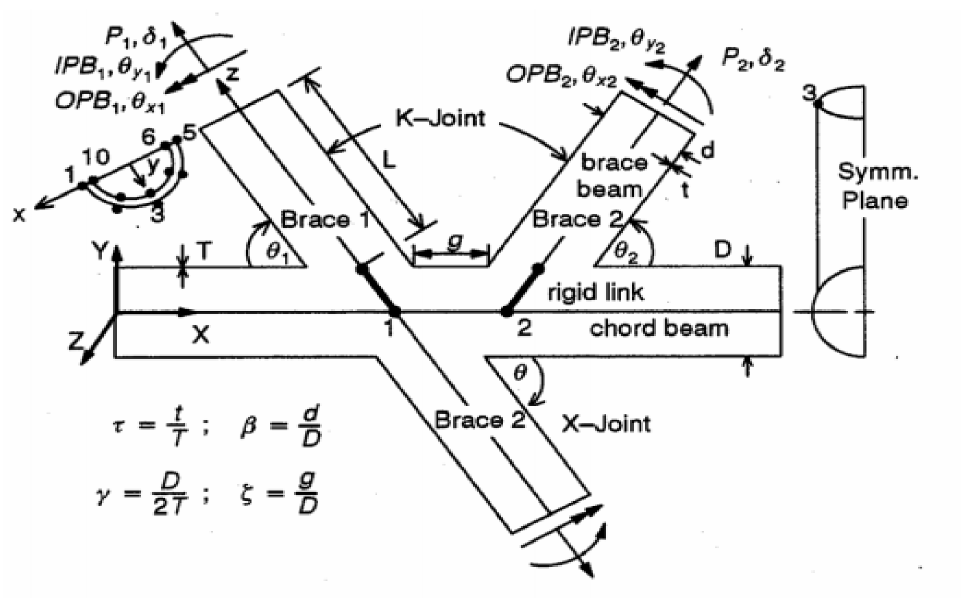

FIGURE 3-3 General joint geometry. (DNV-OS-J101 (2004))

Tubular joints' parametric expression for calculation are shown in following.

According to DNV-OS-J101 (2004), for single-brace joint (Y), the non-dimensional influence factor expression for local joint flexibility are:

$$
\begin{aligned}
f_{axl} &= 5.69\tau^{-0.111}\exp(-2.251\beta)\gamma^{1.791}\sin^{1.700}\theta \\
f_{ipb} &= 1.39\tau^{-0.238}\beta^{-2.245}\gamma^{1.898}\sin^{1.240}\theta \qquad (3.12) \\
f_{opb} &= 55\tau^{-0.220}\exp(-4.076\beta)\gamma^{2.417}\sin^{1.883}\theta
\end{aligned}
$$

For X joint, the non-dimensional influence factor expression for local joint flexibility are:

$$
\begin{aligned}
f_{axl_1}^{\delta_1} &= 8.94\tau^{-0.198}\exp(-2.759\beta)\gamma^{1.791}\sin^{1.700}\theta \\
f_{ipb_1}^{\theta_{y_1}} &= 67.60\tau^{-0.063}\exp(-4.056\beta)\gamma^{1.892}\sin^{1.255}\theta \\
f_{opb_1}^{\theta_{x_1}} &= 73.95\tau^{-0.300}\exp(-4.478\beta)\gamma^{2.367}\sin^{1.926}\theta \qquad (3.13) \\
f_{opb_1}^{\delta_1} &= \tau^{-0.1}(-353 + 1197\beta - 1108\beta\sin\theta - 40\beta\gamma + 50\gamma\sin\theta) \\
f_{opb_1}^{\theta_{y_2}} &= \tau^{-0.1}(26 + 75\beta^2 - 8.5\beta^2\sin\theta + 85\beta^2\gamma - 7.4\gamma\sin\theta) \\
f_{opb_1}^{\theta_{x_2}} &= \tau^{-0.1}(2249 - 5879\beta + 5515\beta\sin\theta + 221\beta\gamma - 358\gamma\sin\theta)
\end{aligned}
$$

For K joint, the non-dimensional influence factor expression for local joint flexibility are:

i) Gapped Joints

$$
\begin{aligned}
f_{axl_1}^{\delta_1} &= 5.90\tau^{-0.114}\exp(-2.163\beta)\gamma^{1.869}\varsigma^{0.009}\sin^{1.869}\theta_1\sin^{-0.089}\theta_2 \\
f_{ipb_1}^{\theta_{y_1}} &= 52.2\tau^{-0.119}\exp(-3.835\beta)\gamma^{1.934}\varsigma^{0.011}\sin^{1.417}\theta_1\sin^{-0.108}\theta_2 \\
f_{ipb_1}^{\theta_{x_1}} &= 49.7\tau^{-0.251}\exp(-4.165\beta)\gamma^{2.449}\varsigma^{0.004}\sin^{1.865}\theta_1\sin^{0.054}\theta_2 \\
f_{axl_1}^{\delta_2} &= 3.93\tau^{-0.113}\exp(-2.198\beta)\gamma^{1.847}\varsigma^{-0.056}\sin^{0.837}\theta_1\sin^{0.784}\theta_2 \qquad (3.14) \\
f_{ipb_1}^{\theta_{y_2}} &= f_{ipb_1}^{\theta_{y_1}} - 1.83\tau^{-0.212}\beta^{-2.102}\gamma^{1.872}\varsigma^{0.020}\sin^{1.249}\theta_1\sin^{0.060}\theta_2 \\
f_{ipb_1}^{\theta_{x_2}} &= 4.37\tau^{-0.295}\exp(-3.814\beta)\gamma^{2.875}\varsigma^{-0.149}\sin^{0.885}\theta_1\sin^{1.109}\theta_2
\end{aligned}
$$

Where δ and Θ_y and Θ_x = Axial Deflection and IPB and OPB Rotations

Subscripts 1 and 2 =Brace 1 and Brace 2

ii) Overlapped Joints

$$f_{axl_1}^{\delta_1} = 3.91\exp(-2.265\beta)\gamma^{2.010}\varsigma^{-0.009}\sin^{1.811}\Theta_1\sin^{-0.029}\Theta_2$$

$$f_{ipb_1}^{\Theta_{y_1}} = 1.86\beta^{-2.093}\gamma^{1.766}\varsigma^{-0.029}\sin^{0.711}\Theta_1\sin^{0.036}\Theta_2$$

$$f_{ipb_1}^{\Theta_{x_1}} = 54.2\exp(-3.959\beta)\gamma^{2.403}\varsigma^{0.001}\sin^{1.865}\Theta_1\sin^{-0.009}\Theta_2$$

$$f_{axl_1}^{\delta_2} = 0.48\beta^{-1.269}\gamma^{2.032}\varsigma^{0.072}\sin^{0.949}\Theta_1\sin^{0.954}\Theta_2 \quad (3.15)$$

$$f_{ipb_1}^{\Theta_{y_2}} = 0.75\beta^{-3.000}\gamma^{2.063}\varsigma^{1.079}\sin^{0.533}\Theta_1\sin^{0.586}\Theta_2$$

$$f_{ipb_1}^{\Theta_{x_2}} = 1.16\beta^{-2.068}\gamma^{2.550}\varsigma^{0.117}\sin^{1.090}\Theta_1\sin^{1.089}\Theta_2$$

ς= Absolute value of g/D

f_{axl} = LJF_{axl}*ED ; f_{ipb} =LJF_{ipb}*ED^3 ; f_{opb} =LJF_{opb}*ED^3

Structural Reliability Analysis

For the structural reliability analysis, it will be computed by using MATLAB, the FORM and Monte Carlo Stimulation (MCS) methods will be used to determine the reliability of the results. FORM, which is also referring as the First-Order Reliability Method, is a further development of First-Order Secondary Moment method (FOSM). The FORM will be used to determine the reliability index of the jacket structure.

According to Choi at al. (2007), the approximate limit-state function at the mean is written as:

$$\bar{g}(x)=g(\mu_x)+\nabla g(\mu_x)^T(X_i-\mu_{x_i}) \qquad (3.16)$$

Where $\mu_x = \{\mu_{x_1}, \mu_{x_2}, \mu_{x_3}, \mu_{x_4..}\ \mu_{x_n}\}^T$ and $\nabla g\ (\mu_x)$ is the gradient of g evaluated at μ_x. The mean value of approximate limit-state function is:

$$\mu_{\bar{g}}= g(\mu_x) \qquad (3.17)$$

The limit-state approximation function standard deviation is:

$$6_{\bar{g}} =\sqrt{(\mathrm{Var}[\bar{g}(x)]} \qquad (3.18)$$

$$6_{\bar{g}} =\left[\sum_{i=1}^{n}\left(\frac{\partial g(\mu_x)}{\partial x_1}\right)^2 6_{x_i}^2\right]^{1/2}$$

While the reliability index β is defined as:

$$\beta=\frac{\mu_{\bar{g}}}{6_{\bar{g}}} \qquad (3.19)$$

However, if the limit-state function is nonlinear, mean value method will be used to linearize the original limit-state function to obtain the approximate limit-state surface at the mean value point. While the β in equation 3.23, will be known as Mean Value First-Order Secondary Moment method (MVFOSM). The complex probability problem will be change by MVFOSM to a simpler problem that forms relationship between mean, standard deviation and the reliability index.

If the failure surface is a hyper plane, which can be defined as a linear-failure function for independent variables of n-dimensional space:

$$\bar{g}(x)=c_0+\sum_{i=1}^{n} c_i\, x_i \tag{3.20}$$

$$\mu_{\bar{g}}=c_0+c_1\mu_{x_1}+c_2\mu_{x_2}+\ldots c_n\mu_{x_n} \tag{3.21}$$

$$\sigma_{\bar{g}}=\sqrt{\sum_{i=1}^{n} c_1^2\, \sigma_{x_i}^2} \tag{3.22}$$

MVFOSM reliability index β is defined as:

$$\beta=\frac{\mu_{\bar{g}}}{\sigma_{\bar{g}}} \tag{3.23}$$

Whereas the Monte Carlo Method, will be used to generate random variables through predetermined probability distribution function.

The probability of failure provided by Monte Carlo Stimulation is as follows:

$$p_f=\frac{N_f}{N} \tag{3.24}$$

Where N_f represent the trials number when g (‘) is violated out of N experiment conducted while g (‘) represent failure for the samples of random variables.

As for the enhancement of the structural reliability, will be focusing on the joints of the jacket structure. In this project a MATLAB code known as Finite Element Reliability Using Matlab (FERUM) will be used to perform the reliability analysis.

The simplified methodology of the project is shown in the following flow chart (Figure 3-4)

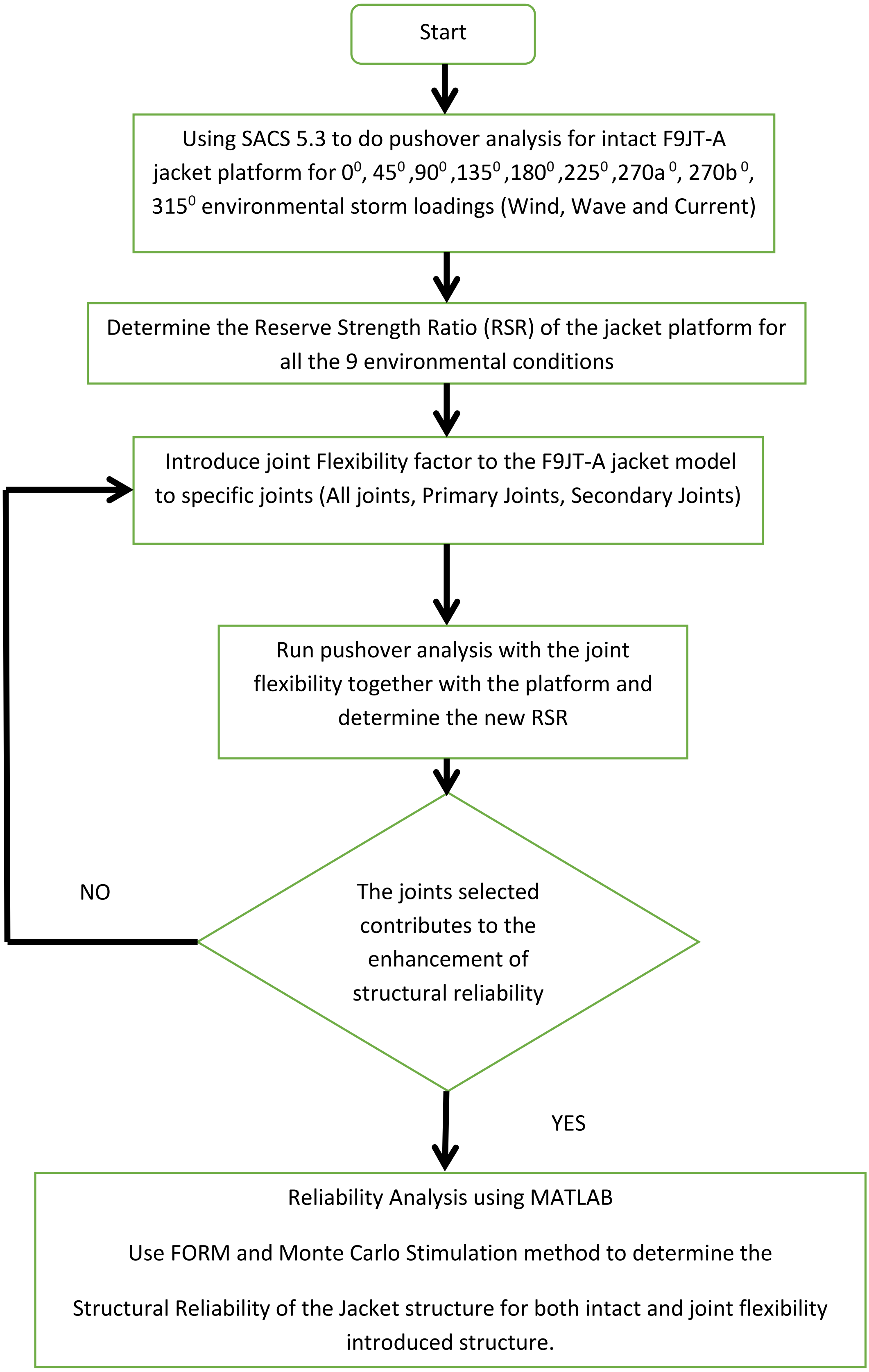

FIGURE 3-4 Flow chart of Methodology

3.2 Project Activities

Activities slated throughout this project are illustrated in the chart below:

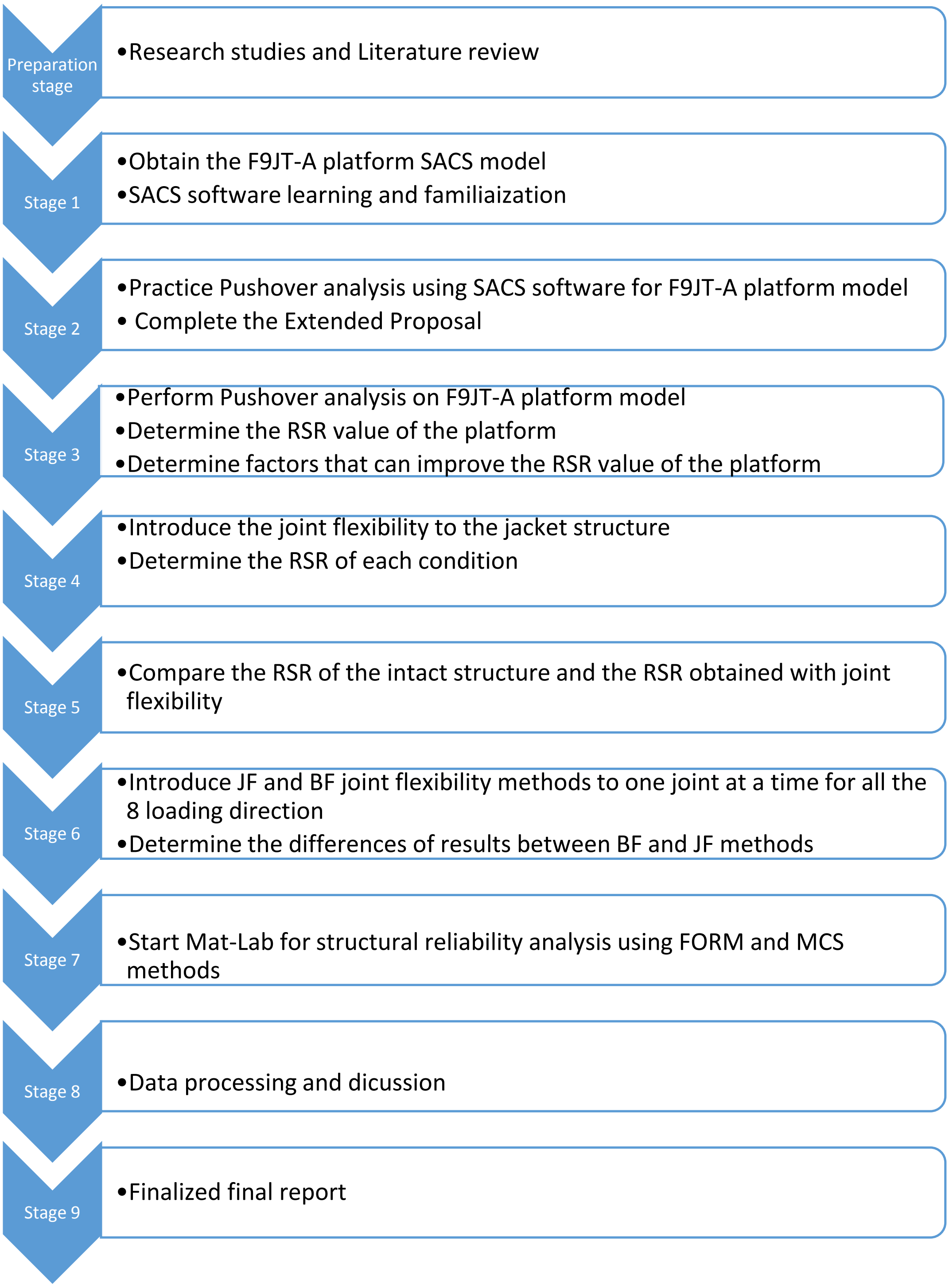

FIGURE 3-5 Project activities of FYP

3.3 Key Project Milestone

FYP 1

TABLE 3-1 Project key milestone for FYP 1

Key Activities	Week
Choose FYP tittle	1
Practice SACS software	3
Submission of Extended Proposal	6
Determine the RSR of Intact Structure	8
Proposal Defence	9
Introduce Joint Flexibility to the F9JT-A structure	10
Submission of Interim report	13

FYP 2

TABLE 3-2 Project key milestone for FYP 2

Key Activities	Week
Introduce Joint flexibility to one joint at a time to the F9JT-A Structure	1
Submission of Progress Report	7
Evaluate Results	8
Structural Reliability Analysis	9
Pre-Sedex	12
Submission of Dissertation (Soft Bound)	12
Submission of Technical Paper	13
Viva	14

3.4 Gantt Chart

TABLE 3-3 Grantt Chart for FYP 1

FYP1														
Main Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of topic														
Preliminary Literature review														
SACS 5.3 Software Practice														
Extended Proposal														
Detailed Literature Review														
Pushover Analysis using SACS for F9JT jacket structure														
Determine the factor that contribute to enhancement of structural reliability														
Introduce the joint flexibility to the F9JT jacket structure and determine the RSR														
Proposal Defence														
Compare and analyse the RSR obtained														
Draft Interim report														
Final Interim Report														

TABLE 3-4 Grantt Chart for FYP 2

FYP2														
	Week													
Main Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Continue Non-linear pushover analysis that include JF and BF joint flexibilities for various joints														
Refine Literature review and Methodologies														
Tabulation of Results for the effect of joint flexibility to the F9JT-A Platform														
Submission of Progress Report														
Structural Reliability Analysis of F9JT-A Platform														
Detail Analysis of results obtained														
Prepare Draft Report														
Pre-Sedex														
Submission of Dissertation														
Submission of Technical Paper														
Viva														

Chapter 4: RESULTS AND DISCUSSION

4.1 Results

4.1.1 RSR of intact structure, JF joint flexibility and BF local joint flexibility introduced structure.

Results of intact structure

Results obtained from pushover analysis for intact structure are tabulated in table 4-1.

TABLE 4-1 The results of pushover analysis for intact structure of F9JT-A

Direction(^{o})	Intact Base shear(kN)	Intact Base Shear at Collapse (kN)	Intact RSR
0	8842	38415.24	4.344632
45	19909.13	35834.59	1.799907
90	10020.02	35769.84	3.569837
135	10189.84	33969.4	3.333654
180	10018.5	38037.34	3.79671
225	10013.65	27543.84	2.750629
270a	10319.15	30484.16	2.954135
270b	10320.49	30485.84	2.953914
315	10012.52	29398.06	2.93613

Referring to table 4-1, base shear, base shear at collapse and RSR are tabulated with respect to the direction of environmental loading. It can be seen that the highest RSR for the intact structure at 0^o direction with RSR value of 4.344632, while the lowest RSR obtained is at 45^o with RSR value of 1.799907. Graph illustration are shown is figure 4-1

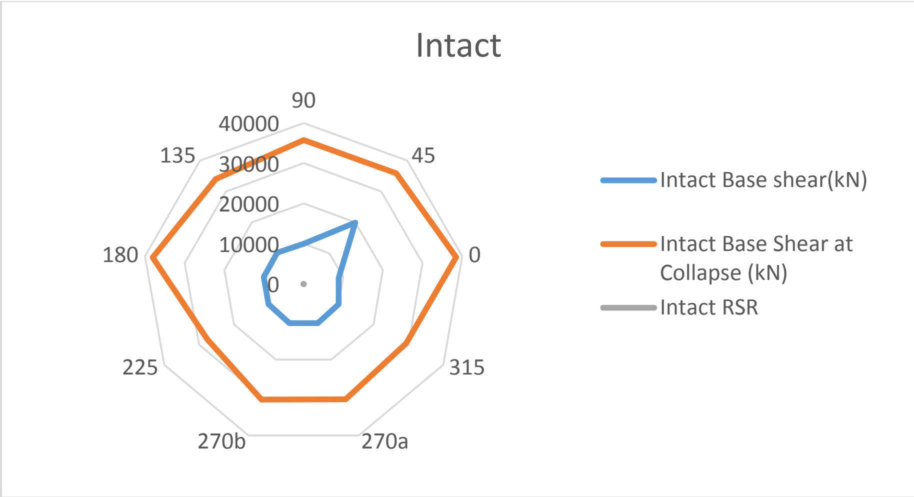

FIGURE 4-1 The plot between base shear, base shear at collapse and RSR of intact structure.

Results with local Joint flexibility introduced

Structure with local joint flexibility introduced in each and every joints are referred in this report for local joint flexibility introduced structure, while structure with local joint flexibility introduced to one joint at a time can be referred in **APPENDIX A**

Results of intact structure with Fessler local joint flexibility introduced.

Results from pushover analysis for intact structure with JF (Fessler) local joint flexibility introduced to all the joints, are tabulated in table 4-2.

TABLE 4-2 The results of pushover analysis for intact structure of F9JT-A with JF method.

Direction(^{o})	JF base shear(kN)	JF base shear at collapse (kN)	JF RSR
0	8841.45	36346.1	4.110875
45	19912.35	35770.48	1.796397
90	10015.46	31822.33	3.177321
135	10189.1	33961.37	3.333108
180	10018.15	38015.33	3.794646
225	10014.29	27546.73	2.750742
270a	10323.29	30499.67	2.954453
270b	10325.16	32460	3.143777
315	10019.11	29326.94	2.9271

As shown in table 4-2, base shear, base shear at collapse and RSR are tabulated with respect to the direction of environmental loading. It can be seen that the highest RSR for the structure that apply JF local joint flexibility to all the joints of the structure is at 0^o direction with RSR value of 4.110875, while the lowest RSR obtained is at 45^o with RSR value of 1.796397. Graph illustration are shown is figure 4-2.

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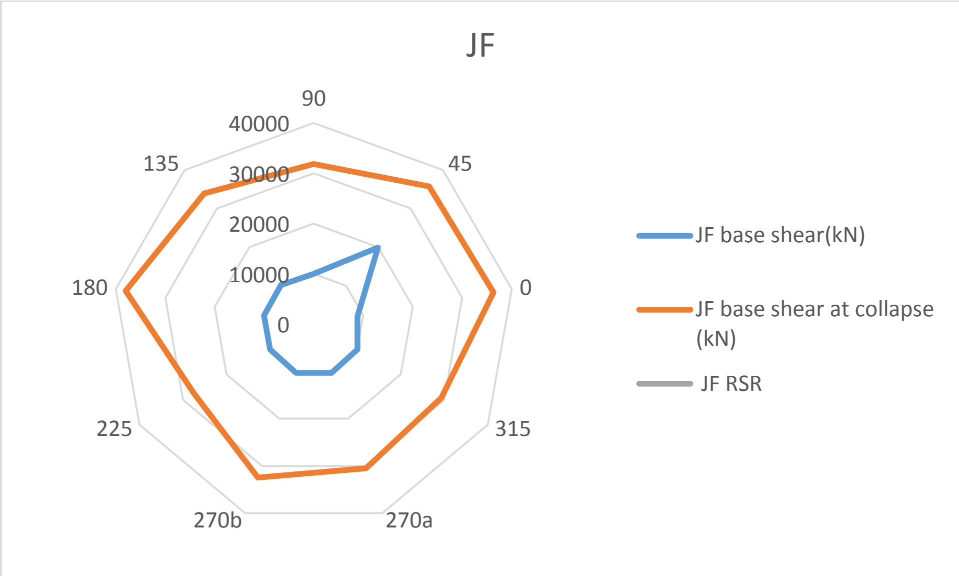

FIGURE 4-2 The plot between base shear, base shear at collapse and RSR of intact structure with JF local joint flexibility

Results of intact structure with Buitrago local joint flexibility introduced.

Results from pushover analysis for intact structure with BF (Buitrago) local flexibility introduced to all the joints, are tabulated in table 4-3.

TABLE 4-3 The results of pushover analysis for intact structure of F9JT-A with BF method.

Direction(°)	BF base shear(kN)	BF base shear at collapse (kN)	BF RSR
0	8876.44	39838.36	4.488101
45	19913.51	35764.16	1.795975
90	10022.3	43369.63	4.327313
135	10190.54	34006.52	3.337068
180	10019.87	38034.8	3.795937
225	10016.07	27549.04	2.750484
270a	10323.45	32439.93	3.142354
270b	10327.04	32456.9	3.142904
315	10020.17	29310.02	2.925102

Based on table 4-3, base shear, base shear at collapse and RSR are tabulated with respect to the direction of environmental loading. It can be seen that the highest RSR for the structure that apply BF local joint flexibility to all the joints of the structure is at 0° direction with RSR value of 4.488101, while the lowest RSR obtained is at 45° with RSR value of 1.795975. Graph illustration are shown is figure 4-3.

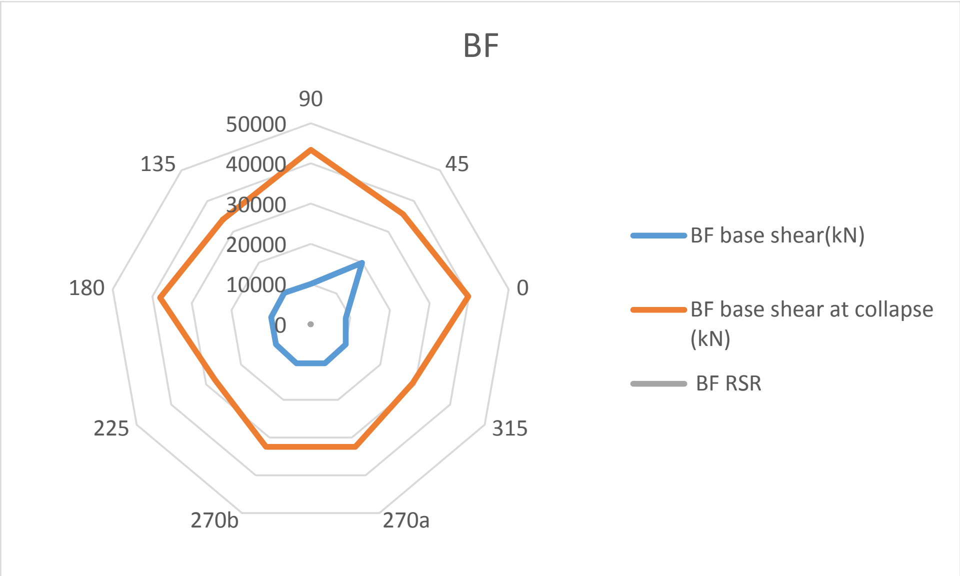

FIGURE 4-3 The plot between base shear, base shear at collapse and RSR of intact structure with BF local joint flexibility.

The comparison of base shear, base shear at collapse and RSR between the intact structure, JF and BF introduced to the structure are illustrated in figure 4-4, 4-5 and 4-6.

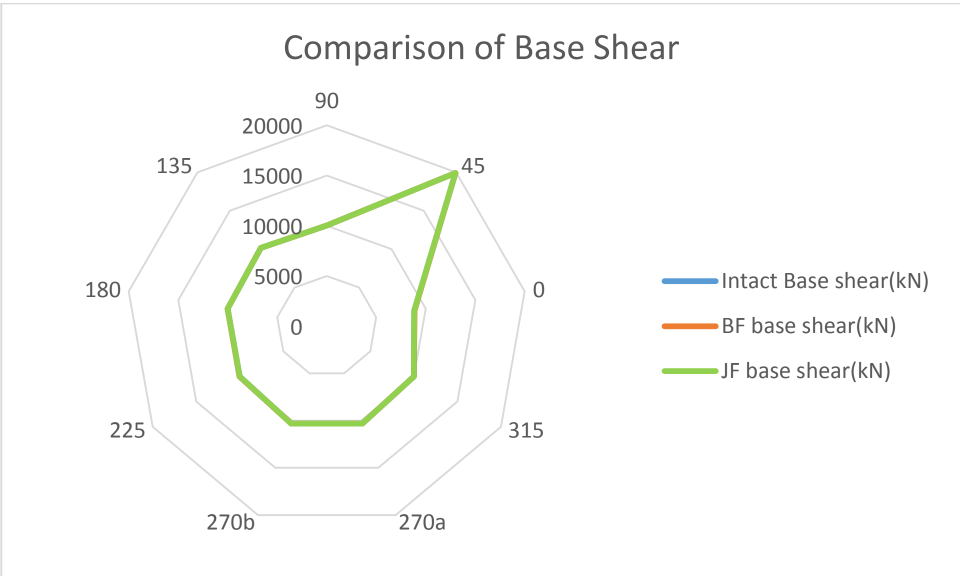

FIGURE 4-4 The comparison of designed base shear between intact structure and structure with JF and BF local joint flexibility implemented.

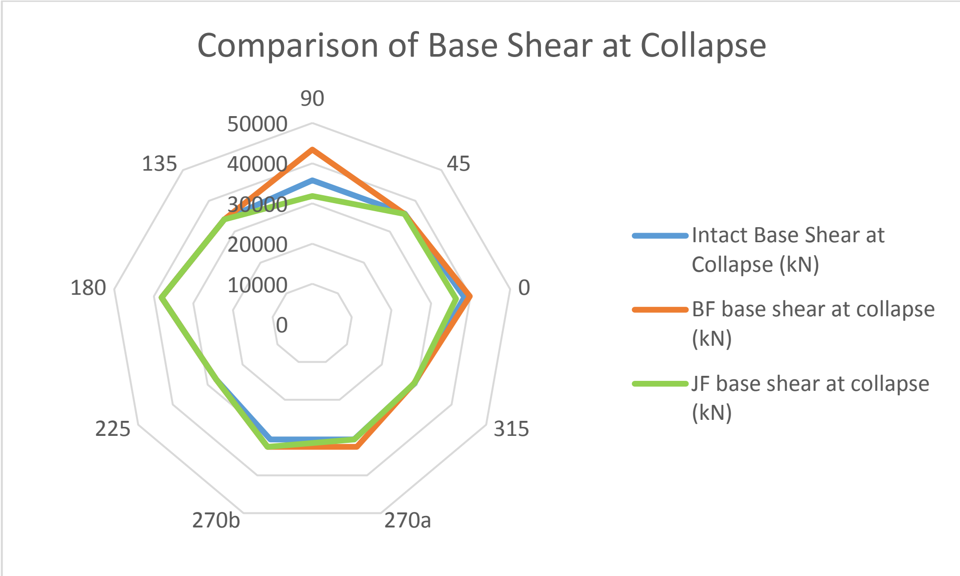

FIGURE 4-5 The comparison of base shear at collapse between intact structure and structure with JF and BF local joint flexibility implemented.

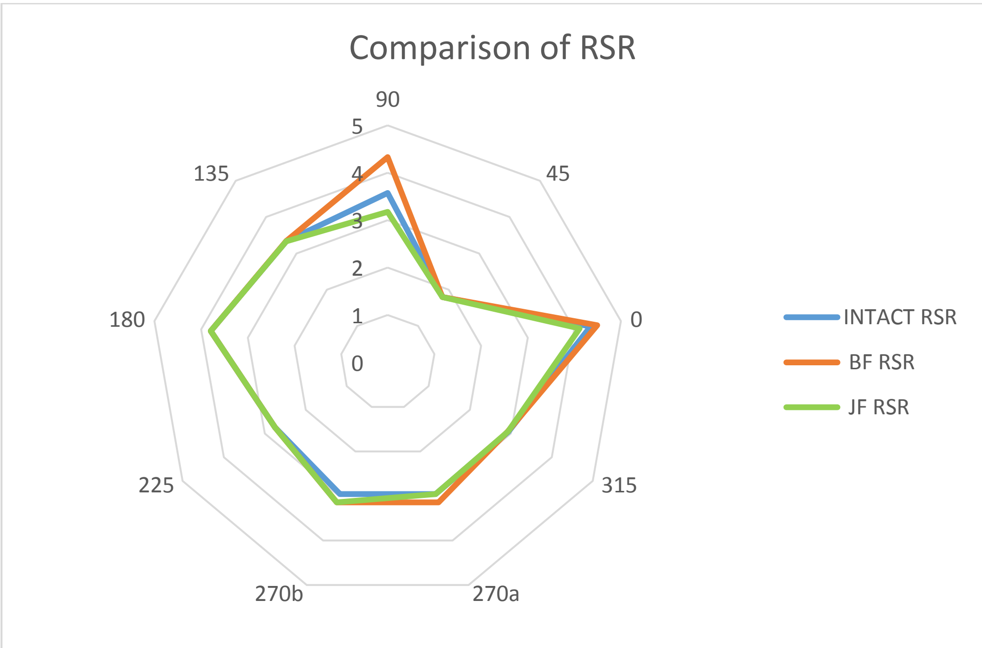

FIGURE 4-6 The comparison of RSR between intact structure and structure with JF and BF local joint flexibility implemented.

4.1.2 The results of displacement in X, Y and Z axis for 0º, 45 º and 90 º environmental loading direction.

Joint 7436, has been taken as the joint for result tabulation in this report to represent the displacement of the structure. Joint 7436 is a joint located in the centre point of the top most layer of the jacket part of the F9JT-A platform.

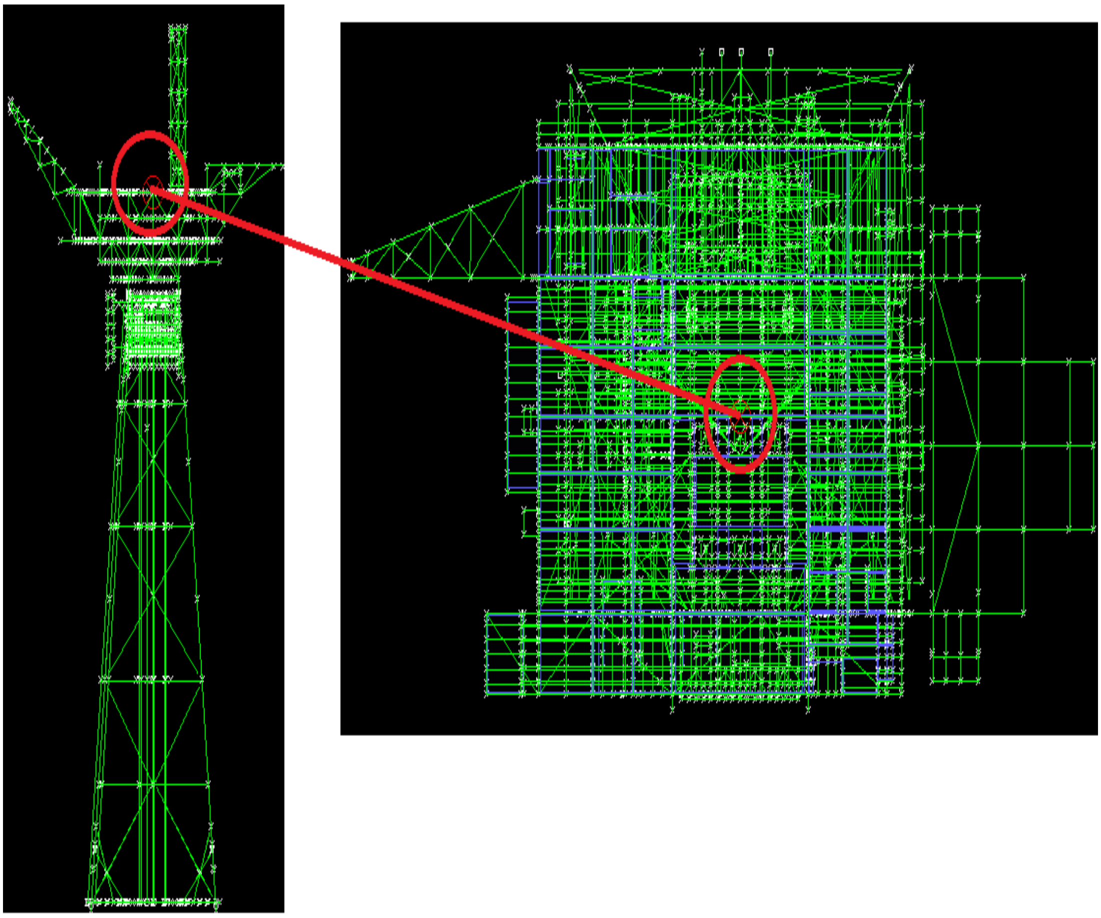

FIGURE 4-7 Location of joint 7436

i) **The following figure 4-8, 4-9, 4-10 are the load factor vs displacement curve for 0 º, 45 º and 90 º in the X- axis.**

The load factor vs displacement curve in X- axis for 0º direction is shown in figure 4-8 below:

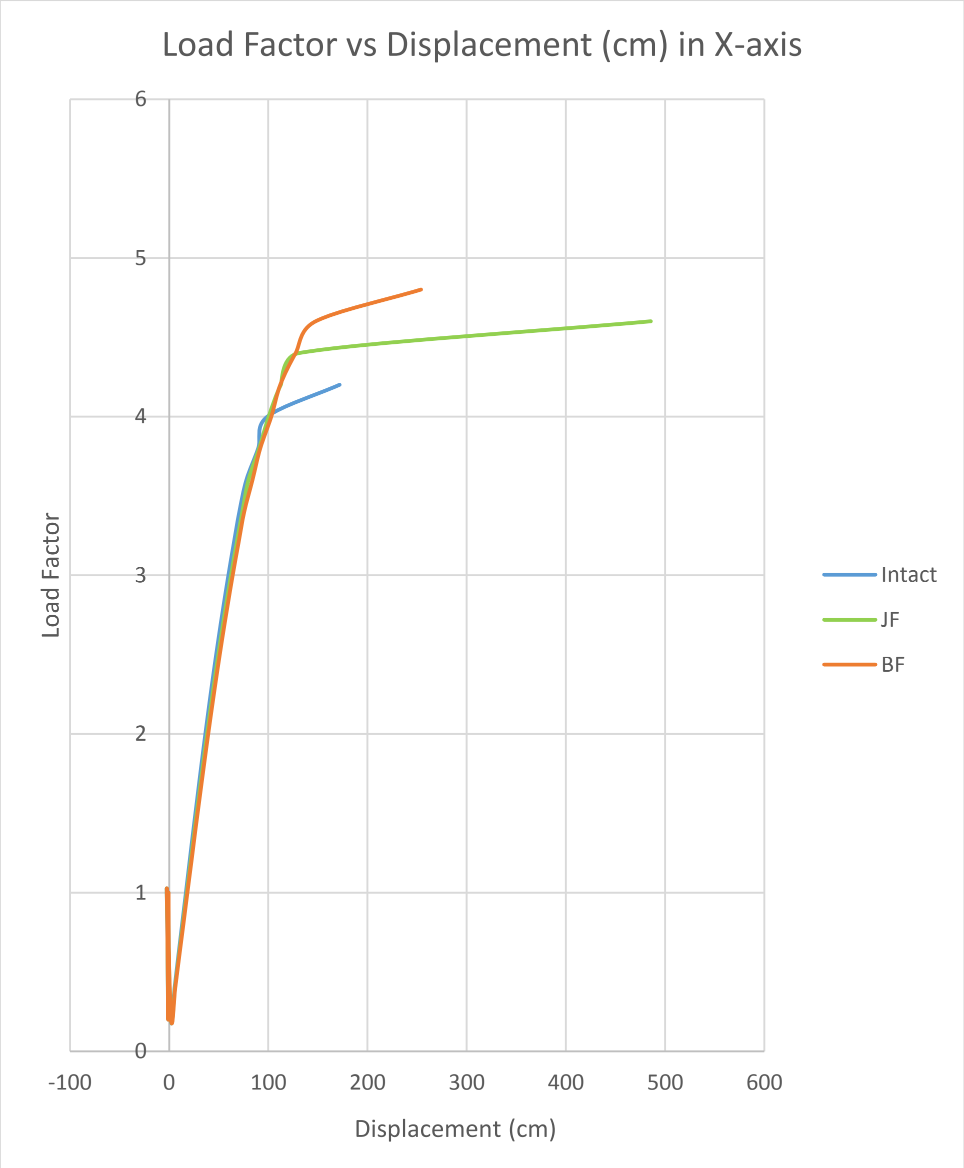

FIGURE 4-8 Load factor vs displacement curve in X- axis for 0º direction.

Based on figure 4-8, it can be seen that the BF local joint flexibility introduced structure have the highest load factor with lower displacement, while the JF local joint flexibility introduce structure has a larger displacement with respect to load factor, as comparing both with the intact structure for displacement in the X- axis for 0º direction.

The load factor vs displacement curve in X- axis for 45º direction is shown in figure 4-9 below:

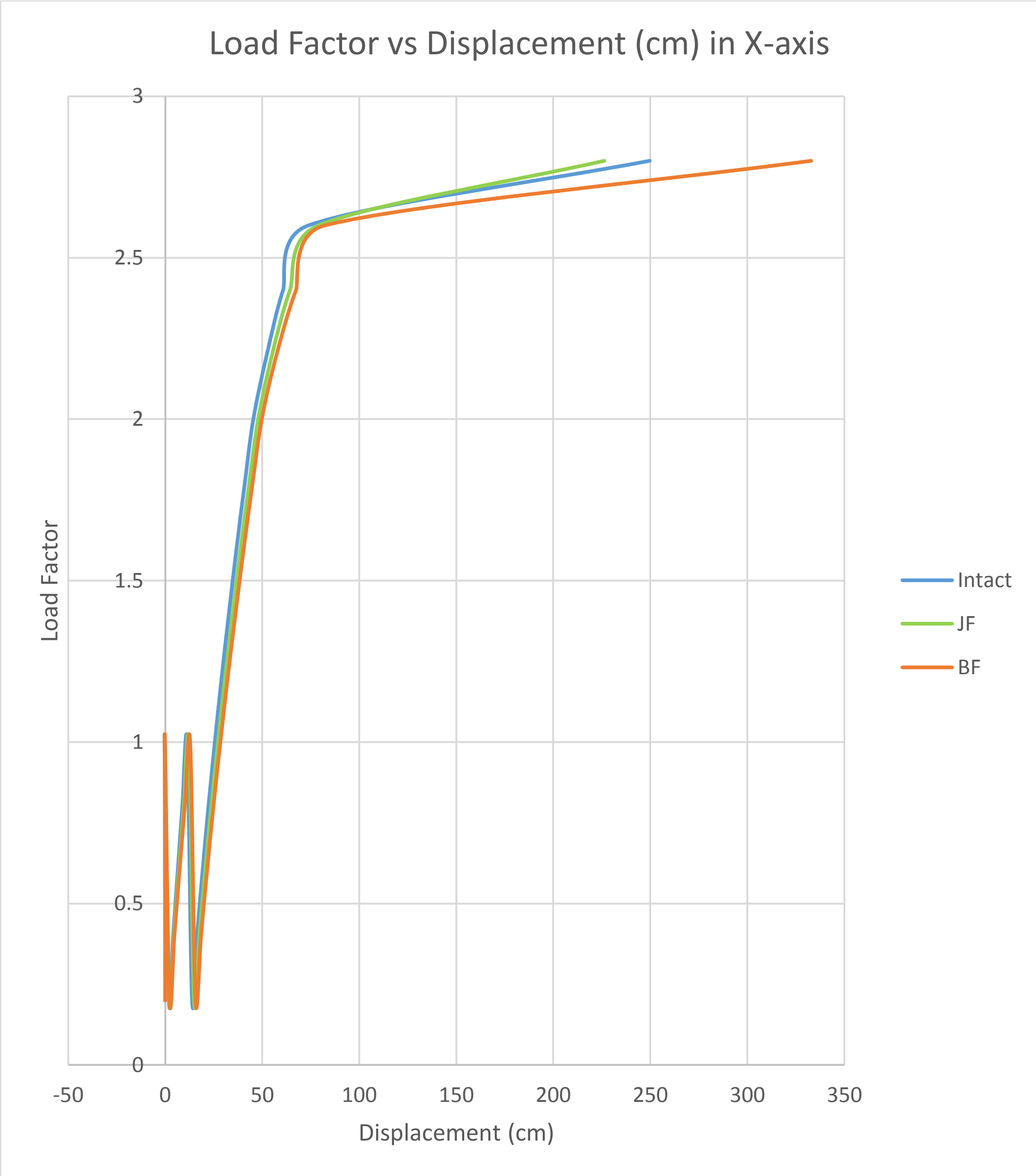

FIGURE 4-9 Load factor vs displacement curve in X- axis for 45º direction

Referring to figure 4-9, it can be seen that the JF local joint flexibility introduced structure have the highest load factor with lower displacement, while the BF local joint flexibility introduce structure has a larger displacement with respect to load factor, as comparing both with the intact structure for displacement in the X- axis for 45º direction.

The load factor vs displacement curve in X- axis for 90º direction is shown in figure 4-10 below:

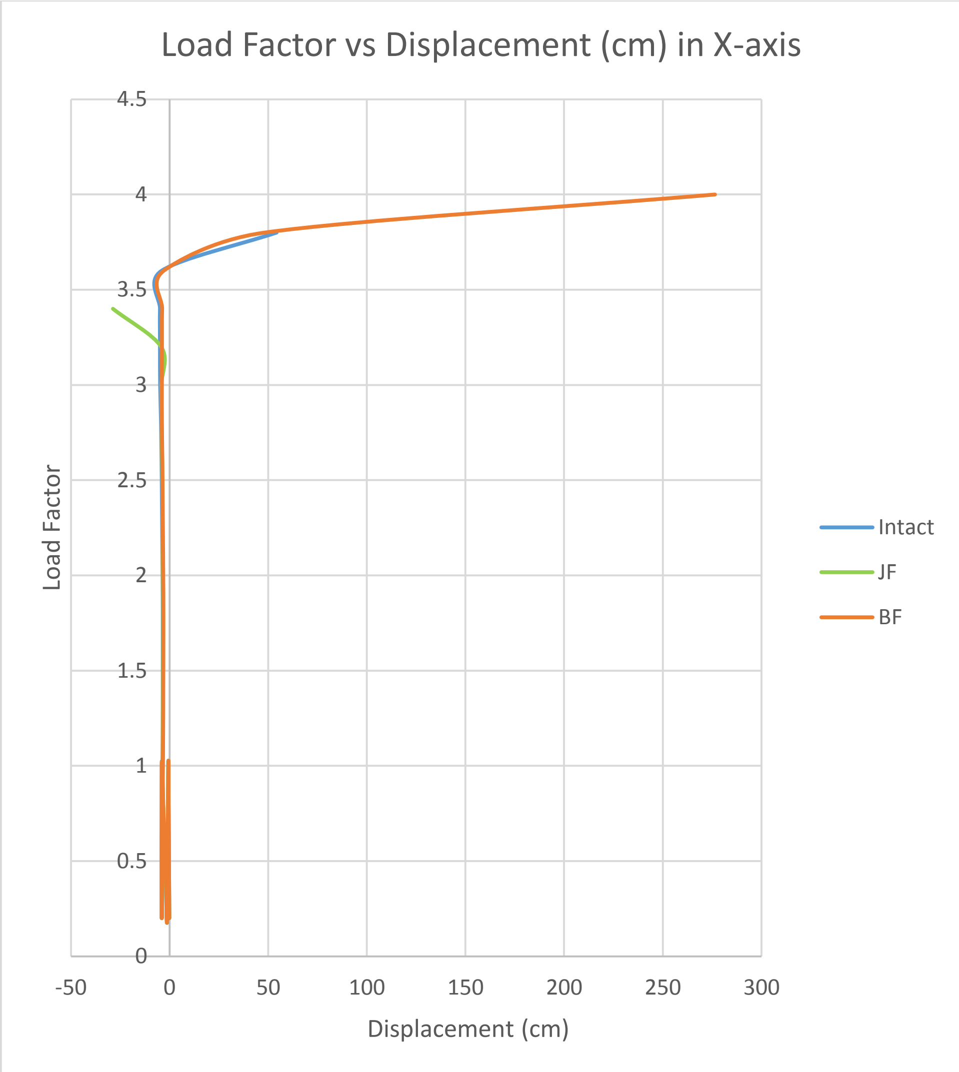

FIGURE 4-10 Load factor vs displacement curve in X- axis for 90º direction

As shown in the figure 4-10 above, it can be seen that the BF local joint flexibility introduced structure has the highest load factor with highest displacement, while the intact structure has a larger displacement with respect to load factor, as comparing with the JF local joint flexibility introduce structure for displacement in the X- axis for 90º direction.

ii) The following figure 4-11, 4-12, and 4-13 are the load factor vs displacement for 0 º, 45 º and 90 º in the Y- axis.

The load factor vs displacement curve in Y-direction for 0º direction is shown in figure 4-11 below:

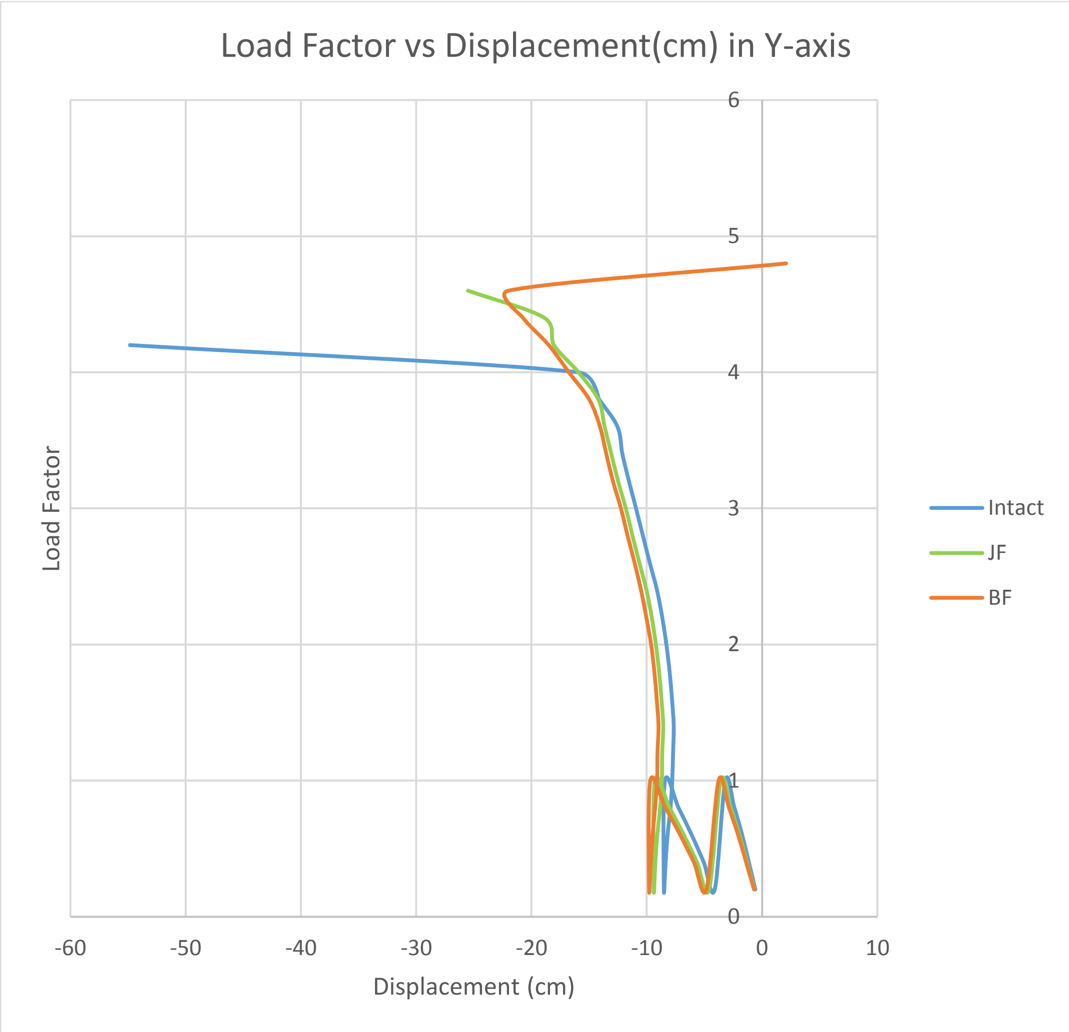

FIGURE 4-11 Load factor vs displacement curve in Y- axis for 0º direction

Based on figure 4-11 , it can be seen that the BF local joint flexibility introduced structure have the highest load factor with lower displacement, while the JF local joint flexibility introduce structure has a lower displacement with respect to load factor, as comparing with the intact structure for displacement in the Y- axis for 0º direction.

The load factor vs displacement curve in Y- axis for 45º direction is shown in figure 4-12 below:

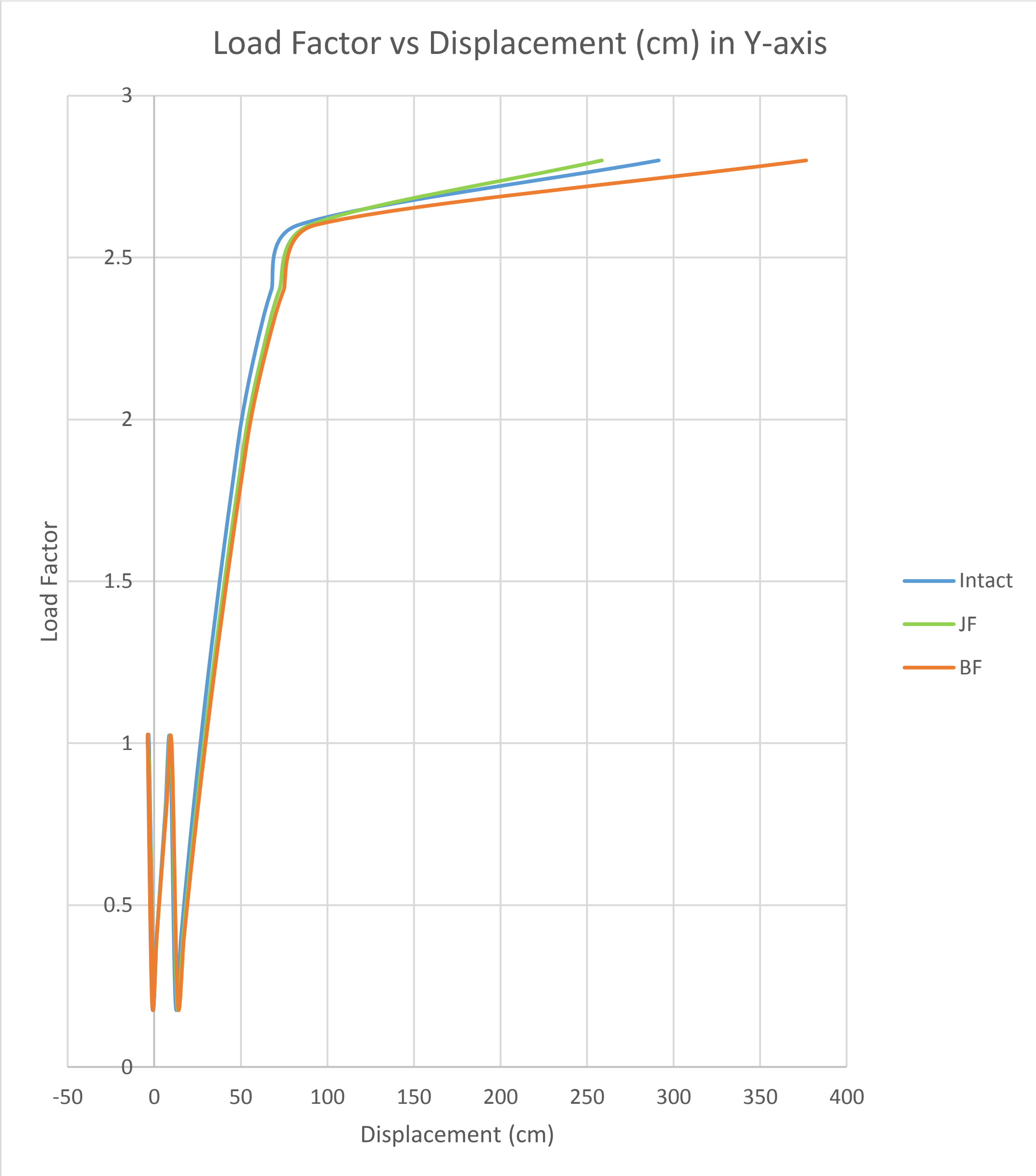

FIGURE 4-12 Load factor vs displacement curve in Y- axis for 45º direction

As referring to the figure 4-12, it can be seen that the JF local joint flexibility introduced structure has the highest load factor with lower displacement, while the BF local joint flexibility introduce structure has a larger displacement with respect to load factor, as comparing with the intact structure for displacement in the Y- axis for 45º direction.

The load factor vs displacement curve in Y- axis for 90º direction is shown in figure 4-13 below:

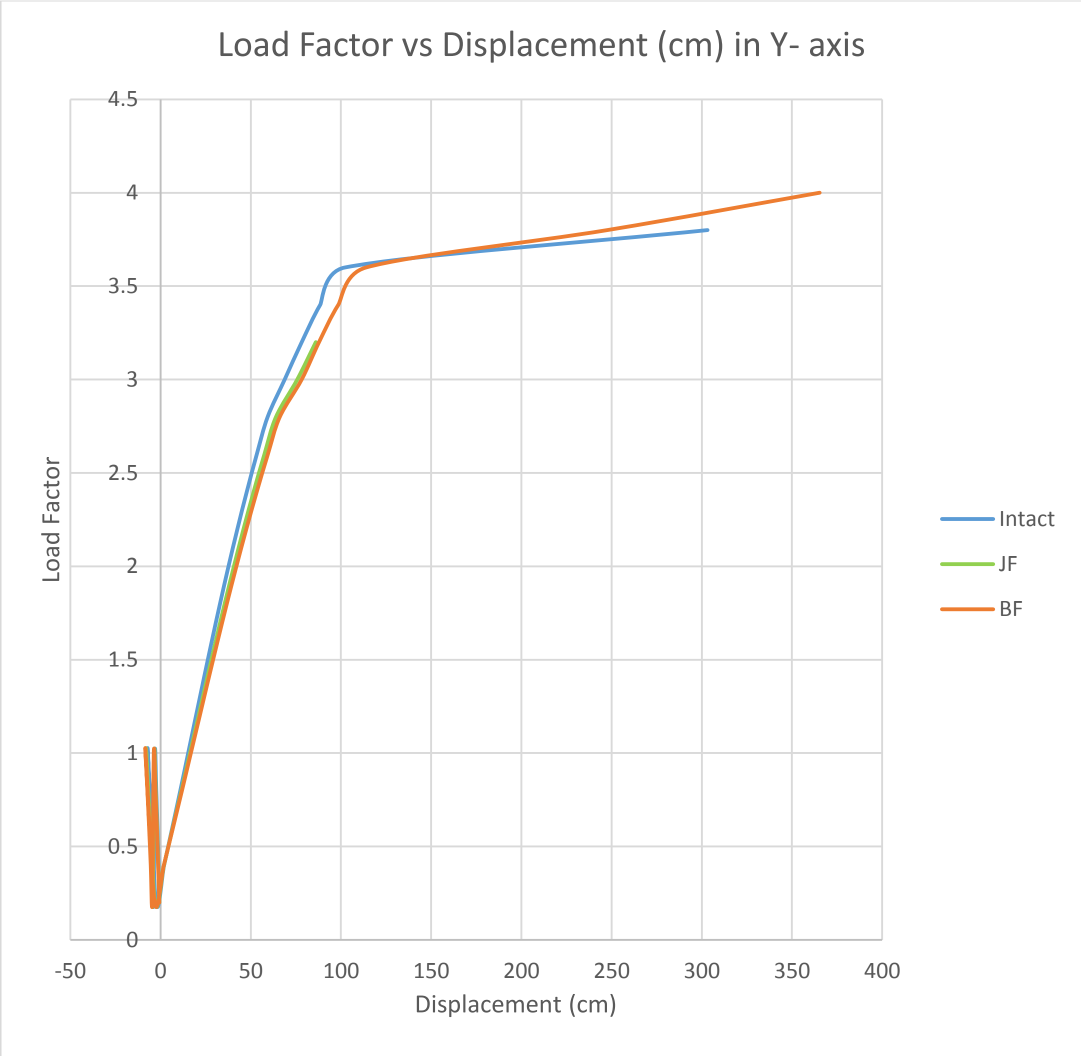

FIGURE 4-13 Load factor vs displacement curve in Y-axis for 90º direction

Based on figure 4-13 above, it can be seen that the BF local joint flexibility introduced structure has the highest load factor with lower displacement, while the JF local joint flexibility introduce structure has a lower capacity of displacement with respect to load factor, as comparing with the intact structure for displacement in the Y-axis for 90º direction.

iii) The following figure 4-14, 4-15 and 4-16 are the load factor vs displacement for 0 º, 45 º and 90 º in the Z- axis.

The load factor vs displacement curve in Z- axis for 0º direction is shown in figure 4-14 below:

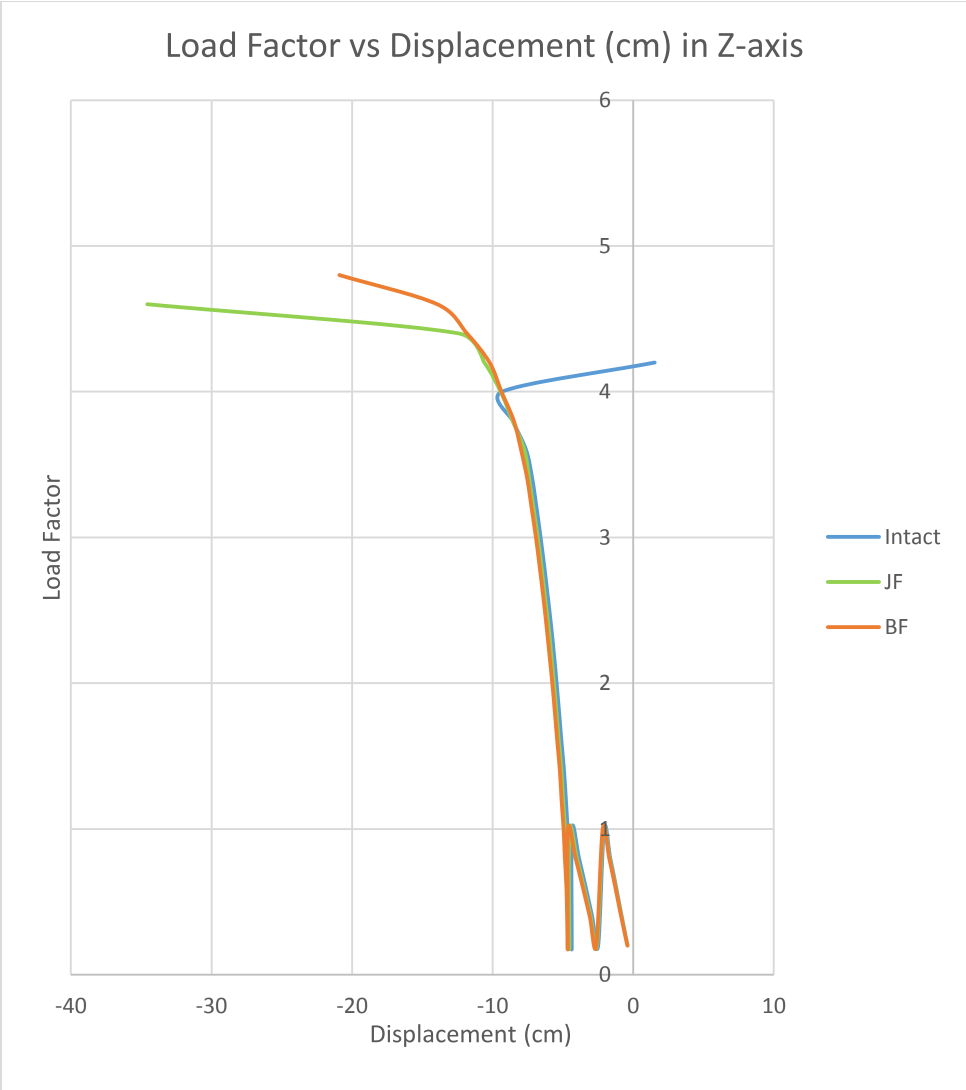

FIGURE 4-14 Load factor vs displacement curve in Z- axis for 0º direction

Based on figure 4-14, it can be seen that the BF local joint flexibility introduced structure has the highest load factor with lower displacement, while the JF local joint flexibility introduce structure has a larger displacement with respect to load factor, as comparing with the intact structure for displacement in the Z- axis for 0º direction.

The load factor vs displacement curve in Z- axis for 45° direction is shown in figure 4-15 below:

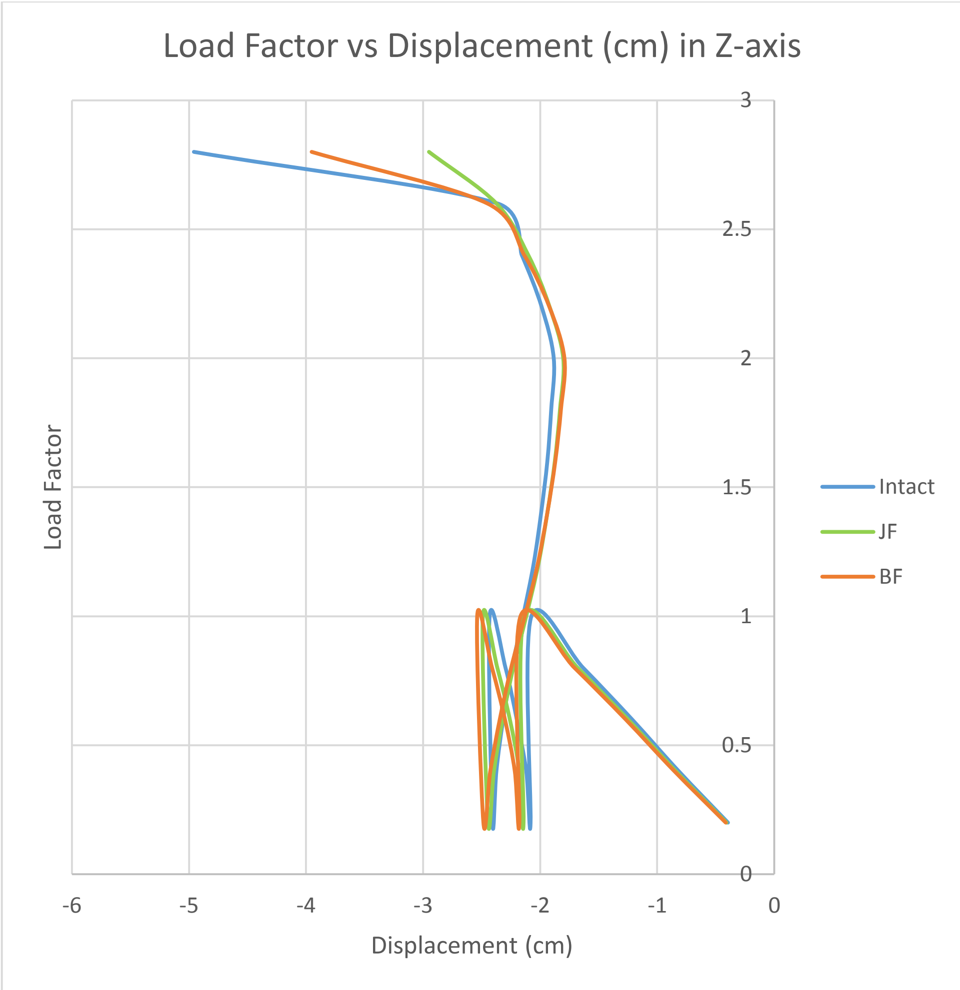

FIGURE 4-15 Load factor vs displacement curve in Z- axis for 45° direction

Based on figure 4-15, it can be seen that the JF local joint flexibility introduced structure has the highest load factor with lower displacement, while the BF local joint flexibility introduced structure has a lower displacement with respect to load factor, as comparing with the intact structure for displacement in the Z- axis for 45° direction.

The load factor vs displacement curve in Z-axis for 90° direction is shown in figure 4-16 below:

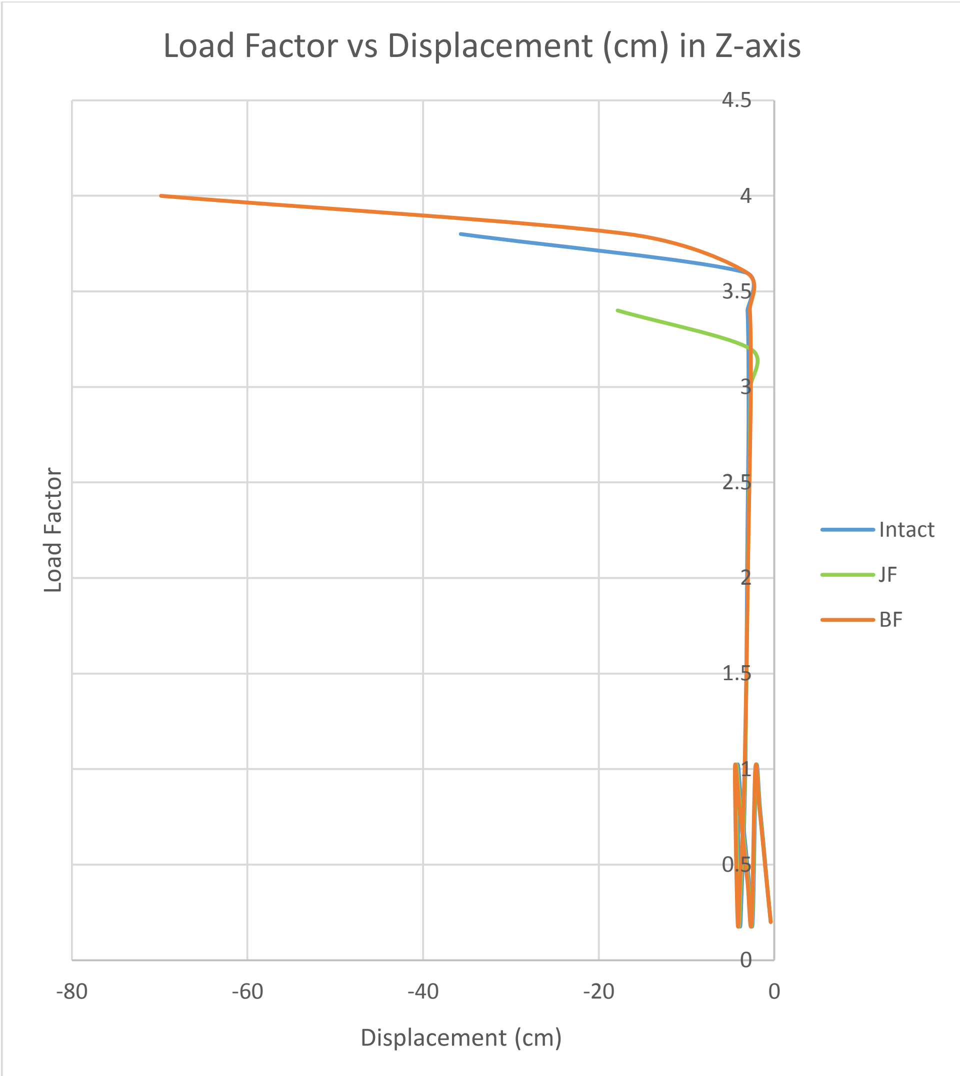

FIGURE 4-16 Load factor vs displacement curve in Z- axis for 90° direction

Referring to figure 4-16, it can be seen that the BF local joint flexibility introduced structure has the highest load factor with lower displacement, while the JF local joint flexibility introduced structure has a lower displacement with respect to load factor, as comparing with the intact structure for displacement in the Z- axis for 90° direction.

4.1.3 The results on effect of joint flexibility on structural reliability of F9JT-A jacket platform.

TABLE 4 Reliability index of Intact structure, and both JF and BF local joint flexibility introduced structure.

Reliability Index, β			
Direction(°)	Intact	JF	BF
0	7.625077	7.45978	7.717915
45	4.127333	4.118397	4.117322
90	6.996537	6.572673	7.613445
135	6.752041	6.752041	6.755798
180	7.206213	7.206213	7.20554
225	6.000648	6.000648	6.00043
270a	6.289692	6.290119	6.530508
270b	6.289395	6.53224	6.531178
315	6.26537	6.253084	6.250357

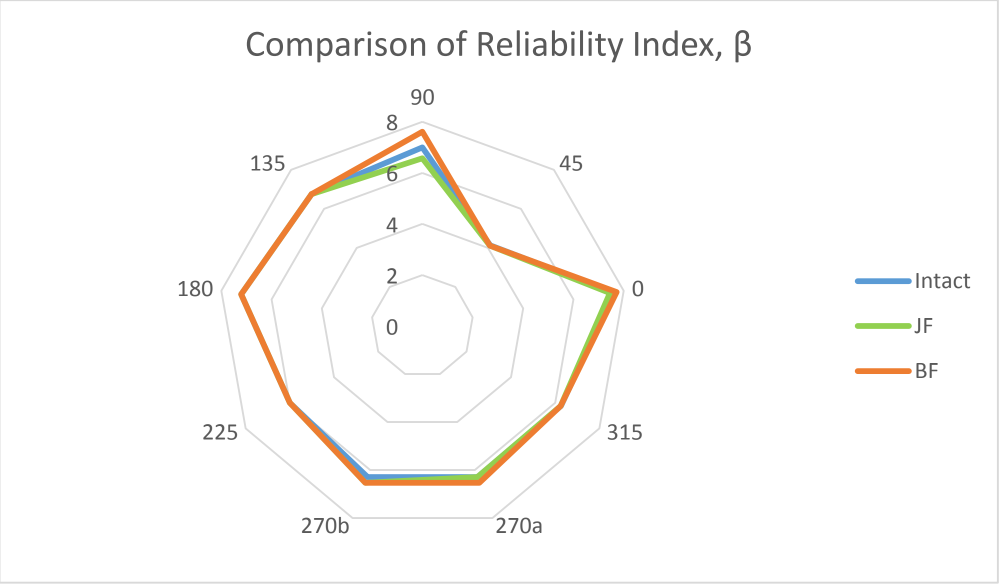

FIGURE 4-17 Reliability Index of Intact structure, JF and BF local joint flexibility introduced structure

Referring to table 4-4 and Figure 4-17, it can be seen that, the highest and lowest reliability index value for all Intact, and both JF and BF local joint flexibility introduced structure are on the same loading direction, which is 0° loading direction for the highest reliability index value while lowest is on 45° loading direction. The highest reliability index value for Intact, JF and BF are 7.625077, 7.45978 and 7.717915 respectively. While the lowest reliability index value for intact, JF and BF are 4.127333, 4.118397 and 4.117322 respectively.

TABLE 4-5 Probability of Failure of Intact, and both JF and BF joint flexibility introduced structure

Probability of Failure			
Direction(^{o})	Intact	JF	BF
0	1.22E-14	4.34E-14	5.94E-15
45	1.83E-05	1.91E-05	1.92E-05
90	1.31E-12	2.47E-11	1.33E-14
135	7.29E-12	7.29E-12	7.1E-12
180	2.88E-13	2.88E-13	2.89E-13
225	9.83E-10	9.83E-10	9.84E-10
270a	1.59E-10	1.59E-10	3.28E-11
270b	1.59E-10	3.24E-11	3.26E-11
315	1.86E-10	2.01E-10	2.05E-10

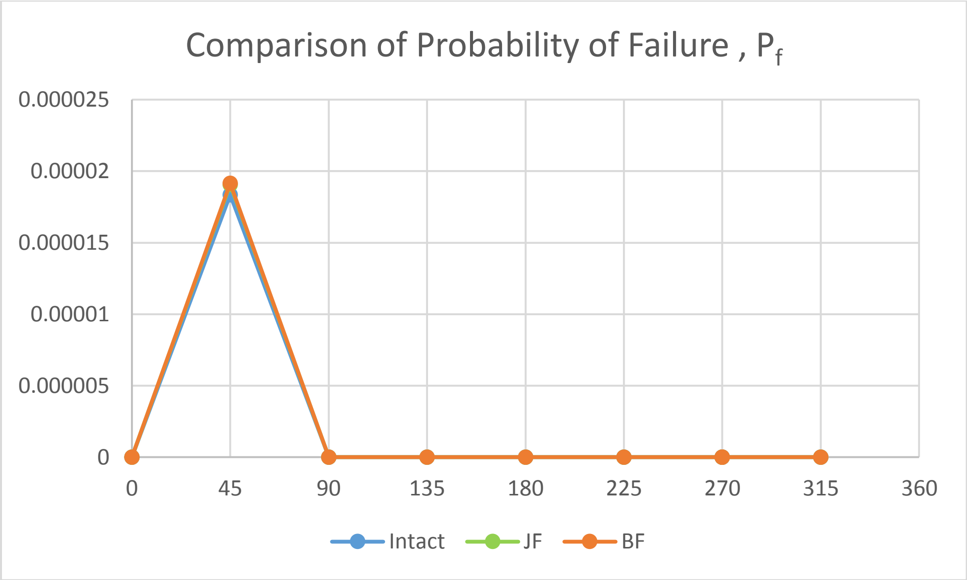

FIGURE 4-18 Probability of Failure P_f

Based on table 4-5 and Figure 4-18, it can be seen that, the highest probability of failure for all Intact, JF and BF are on 45^o loading direction with probability of failure value of 1.83E-05, 1.91E-05 and 1.92E-05 respectively. As for the lowest probability of failure for all Intact, JF and BF structure are on 0^o loading direction with probability of failure value of 1.22E-14, 4.34E-14 and 5.94E-15 respectively.

4.2 Discussion

4.2.1 <u>To determine the Reserve Strength Ratio (RSR) of the intact F9JT-A platform model using SACS 5.3 software</u>.

The RSR values of the intact structure were obtained through Pushover Analysis using SACS 5.3 software and the results had been shown in table 4-1. In this project, 100 years return of storm condition which include wind, wave and current have been applied to the intact structure incrementally until the structure collapsed. It can be seen that, the highest RSR obtained for the F9JT-A intact structure was 4.344 for 0^o environmental loading direction while the lowest RSR value obtained was 1.799 on 45^o environmental loading direction. While for 90^o, 135^o, 180^o, 225^o, $270a^o$, $270b^o$ and 315^o with RSR value of 3.569, 3.333, 3.796, 2.750, 2.954, 2954 and 2.936 respectively. Different loading directions cause different RSR of the jacket structure due to different failure mechanisms in different directions, which may cause by topside failure, jacket members or joint failure, foundation failure or whole system failure.

4.2.2 <u>To determine the effect of local joint flexibilities to the RSR improvement on the F9JT-A jacket structure using SACS 5.3</u>.

Based on the results obtained by implementing all the joints to be flexible through methods suggested by Fessler and Buitrago, the Fessler method gives a less significant results on improvement of RSR value as compare with the results obtained through Buitrago method. There are total of 3 out of 9 environmental loading from pushover analysis gives positive percentage in the differences between the intact structure and the structure that implement the Fessler equation for local joint flexibility (JF method). The highest positive difference between the JF method and the intact structure in term of RSR is 6.427% for $270b^o$, while the other 2 environmental direction were the 225^o and $270b^o$ with RSR improvement of 0.0041% and 0.01075% when compare with the RSR of the intact structure.

While for the RSR obtained using the Buitrago local joint flexibility equations method (BF method) gives more significant results on the improvement of the RSR when compare with the intact structure and the JF method. There are total of 5 out of 9 environment loading directions where the RSR were improved, with the most significant of 21.22% of improvement of RSR for the 90^o environmental loading direction, while the other environmental loadings that have RSR improvement includes 0^o, 135^o, $270a^o$ and $270b^o$ with RSR improvement of 3.3%, 0.1023%, 6.3714% and 6.3979% respectively when it is compare with the intact structure.

Even though there were improvement in term of RSR when the local joint flexibility (JF and BF) were included to the structure, there were RSR values that had a slight decrease in certain environmental loading directions with the maximum decrease in percentage of RSR for JF and BF methods were 10.99% and 0.375% respectively. It can be seen that although there were some decrease RSR values for BF method, the results of BF were far more better as compare with the JF method.

As mentioned by Onoufriou and Forbes (2001), the deformation of the structure will have significant impact on the strength of the jacket platform. In reality, structure's joints are not absolutely rigid when the structure is subjected to lateral loading, it will clearly shows flexibility at the joints. During Pushover analysis the loads were pushed incrementally to the structure in the lateral direction, thus by allowing the joints to have flexibilities will allow the loads to be redistributed to the whole jacket more effective than considering the joints to be rigid, which will in certain direction of loading cause increment and decrement in RSR values when it is compared with intact structure.

The effect of local joint flexibilities are significant when the structure is in the nonlinear behavior which is in the plastic region. It can be seen from the results, that the structure stiffness decrease when joint flexibilities were introduced and the structure was allowed to have a higher displacement compare with the intact structure when subjected to lateral loading. This is because the structure with local joint flexibilities were allowed to deflect more than the intact structure. Based on the results obtained, it can also be seen that the intact structure with rigid joints, have underestimated and overestimated the strength of the structure on certain loading directions, knowing the fact that the joints of the structure are flexible in reality. Thus, to determine a more accurate results of RSR and structure deformation, local joint flexibility should be introduced.

Moreover, when the structure with flexibilities is more ductile as it is allowed to deflect more than the intact structure. The load factor that were applied to the structure with respect to displacement will also increase and on the same time increase the displacement for certain loading directions, this means the structure with joint flexibilities can sustain higher loading compare to the intact structure. This means the structure with local joint flexibility relatively stronger than the intact structure, especially the Buitrago local joint flexibility introduced structure.

4.2.3 <u>To determine the effect of joint flexibility on structural reliability of F9JT-A platform through First-Order Reliability Method (FORM) and Monte-Carlo Stimulation (MCS) methods using MATLAB</u>.

Based on reliability index results obtained as shown in table 4-4, the highest occurrence of percentage in reliability enhancement was from BF local joint flexibility introduced structure when compare with the intact structure with total of 5 out of 9 occurrences of enhancement on loading directions of 0^o,90^o,125^o,$270a^o$ and $270b^o$. The highest percentage of enhancement for Buitrago local joint flexibility introduced structure is on 90^o loading direction with 8.817% of enhancement. While for 0^o, 135^o, $270a^o$ and $270b^o$ have the reliability enhancement of 1.217%, 0.0556%, 3.82875%, and 3.8443% respectively. There are also 4 out of 9 occurrence of decrease in percentage for the value of reliability index. However, the decreased reliability index was not significant when the BF local joint flexibility introduced structure was compared with the intact structure. This can be seen when the maximum percentage of decrement was 0.24256% on 45^o loading direction. While for 180^o, 225^o and 315^o the decrement in the reliability index are 0.0093%, 0.0036% and 0.2396% respectively.

Meanwhile, for the Fessler local joint flexibility introduced structure has no significant results when the reliability index was compared with the intact structure. There were total of 2 out of 9 occurrence on the enhancement of reliability index, with highest percentage of enhancement of 3.8612% on $270b^o$ loading direction and 0.00679% for 315^o loading direction. While the highest decrement in percentage of reliability index was on 0^o loading direction with the 2.1678 %.

By referring to table 4-5, Buitrago local joint flexibility introduced structure gives the lowest probability of failure when it is compared with the Fessler and intact structure. There were total of 5 occurrence for lowest probability of failure for BF joint flexibility introduced structure. They were the 90^o, 0^o, $270b^o$, $270a^o$ and 135^o environmental loading directions with their percentage differences of -98.984%, -51.364%, -79.525%, -79.394% and -2.5566% respectively when compared with the intact structure.

While the highest probability failure when compare with the intact structure were observed from Fessler local joint flexibility introduced structure. There were total of 4 occurrence with high probability of failure. They were 90^o, 0^o, 315^o and 45^o loading directions with percentage difference of 1783.62%, 255%, 8.196% and 3.957% when compared with the intact structure.

Reliability of a structure is the ability of the structure to perform its purpose without failing. In this project the reliability is a function of RSR. Thus the higher the RSR, the lower the probability of failure, higher reliability as a result. Hence, both results of reliability index and probability of failure were control by the RSR value obtained from objective 2. The higher the RSR value of specific structure on specific loading direction, the higher the reliability index and the lower the probability of failure, vice versa.

Since Buitrago local joint flexibility introduced structure shows the higher RSR values occurrence when it was compare with both intact and Fessler local joint flexibility introduced structure, hence, making it the structure which has the highest reliability index and lowest probability of failure. On the same time, it also means the structure is more reliable and has a lower tendency to fail when Buitrago local joint flexibility is introduce to the structure compare to Fessler local joint flexibility and the rigid intact structure.

Chapter 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

To conclude this project, all three objectives have been achieved. The RSR of intact structure, the effect of local joint flexibility using Fessler equations and Buitrago et al equations to the RSR, and the effect of local joint flexibility on the structural reliability of F9JT-A jacket platform have been studied in this project.

Although assumption of rigid joints for jacket structure has been a practice in the offshore industry, however neglecting joint flexibility of the structure will lead to underestimate and overestimating the strength of the structure in the real situation. This is because the joints of jacket platforms are normally welded, may possess some flexibilities cause by the welding methods on connection during fabrication and modifications.

Based on the RSR results obtained from this project, the local joint flexibility method suggested to be apply for the enhancement of structural reliability during pushover analysis is the Buitrago local joint flexibility method. This is because it provide a significant results with the maximum of 21.22% of improvement in terms of RSR value and this method was also suggested by various researchers for fatigue analysis.

In addition to that, based on the results obtained from reliability index and probability of failure, it can be concluded that reliability of the structure increased significantly with maximum of 8.817% for reliability index when Buitrago local joint flexibility was introduced. While the probability of failure of the structure reduced by maximum of 98.98% when the Buitrago local joint flexibility was introduced to the platform when it was compared with the intact F9JT-A jacket platform.

From all the results in this project, the load distributions and deformation effects due to local joint flexibility have a significant impact to the result from analysis of the F9JT-A platform. The effect of joint flexibility is recommended to be taken into various analysis for offshore jacket platforms and Buitrago local joint flexibility method is suggested as it enhanced the structure's reliability.

5.2 Recommendations

As for recommended future work of this project / similar project are as follow:

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i) It is suggested to researchers that carry out similar researches that, experimental full scale test on the tubular joints should be carry out to determine the exact capacity and deflection and to validate the results from results obtained from finite element software that estimate the ultimate strength of the tubular joints.

ii) Lower scale factor can be used depend on the limitation of research facilities if full scale test is not achievable.

iii) Different types of joints including X, Y and K-joints with high sensitive sensor attached should be used for the full scale test. Finite element software should be used to model the exact material properties and dimension of the joint that gone through the full scale test to be analyse and determine the accuracy of the finite element analysis.

iv) Latest finite element software such as SACS 5.7, USFOS 8.7, SESAM, ANSYS or ABAQUS should be used for the non-linear pushover analysis that equipped with latest refined theories to generate a more accurate results in future researches.

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APPENDIX A

Joint flexibility introduced to single chosen joint at a time for JF and BF methods.

(JF) Fessler equation joint flexibility method:

201

Direction	JF base shear(kN)	JF base shear at collapse (kN)	201 JF RSR	% differences	
90	10019.96	35777.95	3.570668	0.023272	Positive
45	19909.12	35928.98	1.804649	0.263455	Positive
0	8841.93	37831.91	4.278694	-1.51771	Negative
315	10012.53	29354.55	2.931781	-0.1481	Negative
270a	10319.19	30455.04	2.951301	-0.09591	Negative
270b	10320.47	30485.82	2.953918	0.000128	Positive
225	10013.64	27543.84	2.750632	9.99E-05	Positive
180	10018.49	38037.34	3.796714	9.98E-05	Positive
135	10189.84	33876.07	3.324495	-0.27475	Negative

202

Direction	JF base shear(kN)	JF base shear at collapse (kN)	202 JF RSR	% differences	
90	10019.82	35765.38	3.569463	-0.01047	Negative
45	19909.11	35573.16	1.786778	-0.72945	Negative
0	8841.87	37832.77	4.27882	-1.5148	Negative
315	10012.53	34539.44	3.449622	17.48872	Positive
270a	10319.12	30484.04	2.954132	-0.0001	Negative
270b	10320.49	30491.25	2.954438	0.017746	Positive
225	10013.64	27543.84	2.750632	9.99E-05	Positive
180	10018.49	38037.11	3.796691	-0.0005	Negative
135	10189.8	33852.51	3.322196	-0.34371	Negative

203

Direction	JF base shear(kN)	JF base shear at collapse (kN)	203 JF RSR	% differences	
90	10019.91	35773.33	3.570225	0.010855	Positive
45	19909.11	35852.17	1.800792	0.049159	Positive
0	8841.91	37770.12	4.271715	-1.67833	Negative
315	10012.53	29354.57	2.931783	-0.14803	Negative
270a	10319.14	30484.06	2.954128	-0.00023	Negative
270b	10320.43	30491.25	2.954455	0.018327	Positive
225	10013.65	27543.63	2.750608	-0.00076	Negative
180	10018.49	38037.39	3.796719	0.000231	Positive
135	10189.84	33880.57	3.324936	-0.2615	Negative

204

Direction	JF base shear(kN)	JF base shear at collapse (kN)	204 JF RSR	% differences	
90	10019.98	35769.66	3.569833	-0.0001	Negative
45	19909.11	35900.36	1.803213	0.183638	Positive
0	8841.67	34792.87	3.935102	-9.42613	Negative
315	10012.52	29345.53	2.930884	-0.17869	Negative
270a	10319.15	30484.06	2.954125	-0.00033	Negative
270b	10320.52	30490.96	2.954402	0.016504	Positive
225	10013.64	27543.84	2.750632	9.99E-05	Positive
180	10018.49	38037.33	3.796713	7.35E-05	Positive
135	10189.82	33886.81	3.325555	-0.24293	Negative

206

Direction	JF base shear(kN)	JF base shear at collapse (kN)	206 JF RSR	% differences	
90	10018.93	35739.92	3.567239	-0.07278	Negative
45	19908.72	33804.72	1.697986	-5.66261	Negative
0	8842.2	39794.31	4.500499	3.58756	Positive
315	10013.41	29353.73	2.931442	-0.15967	Negative
270a	10319.7	32475.31	3.146924	6.526075	Positive
270b	10321.65	32391.12	3.138173	6.23778	Positive
225	10013.65	27544.43	2.750688	0.002142	Positive
180	10018.4	38039.51	3.796965	0.006703	Positive
135	10190.05	33845.37	3.321414	-0.36718	Negative

207

Direction	JF base shear(kN)	JF base shear at collapse (kN)	207 JF RSR	% differences	
90	10019.87	35768.81	3.569788	-0.00138	Negative
45	19909.13	35932.39	1.80482	0.272921	Positive
0	8841.84	37900.47	4.286491	-1.33823	Negative
315	10012.66	29354.53	2.931741	-0.14947	Negative
270a	10319.16	30484.1	2.954126	-0.00029	Negative
270b	10320.5	32403.69	3.13974	6.29085	Positive
225	10013.69	27543.83	2.750617	-0.00044	Negative
180	10018.5	38037.34	3.79671	0	Negative
135	10189.88	33848.39	3.321765	-0.35662	Negative

208

Direction	JF base shear(kN)	JF base shear at collapse (kN)	208 JF RSR	% differences	
90	10018.59	35645.42	3.557928	-0.33361	Negative
45	19909.8	44819.41	2.251123	25.06883	Positive
0	8841.68	39780.86	4.499242	3.558639	Positive
315	10014.29	29355.2	2.931331	-0.16344	Negative
270a	10320.4	32451.85	3.144437	6.441901	Positive
270b	10321.42	30494.66	2.954502	0.019918	Positive
225	10014.41	36014.25	3.596243	30.74254	Positive
180	10018.44	38036.03	3.796602	-0.00285	Negative
135	10189.67	33968.95	3.333665	0.000344	Positive

210

Direction	JF base shear(kN)	JF base shear at collapse (kN)	210 JF RSR	% differences	
90	10020.02	35770.75	3.569928	0.002544	Positive
45	19909.12	35894.37	1.802911	0.166872	Positive
0	8841.81	39774.82	4.498493	3.541393	Positive
315	10012.43	29354.66	2.931822	-0.14673	Negative
270a	10319.08	30484.01	2.95414	0.000186	Positive
270b	10320.57	32279.87	3.127722	5.883977	Positive
225	10013.64	27544	2.750648	0.000681	Positive
180	10018.58	38036.71	3.796617	-0.00245	Negative
135	10189.84	33879.12	3.324794	-0.26577	Negative

301

Direction	JF base shear(kN)	JF base shear at collapse (kN)	301 JF RSR	% differences	
90	10019.85	35685.62	3.561492	-0.23376	Negative
45	19908.86	35932.58	1.804854	0.274811	Positive
0	8842.31	54820.28	6.199769	42.69951	Positive
315	10012.86	37893.5	3.784483	28.89358	Positive
270a	10319.1	30483.17	2.954053	-0.00276	Negative
270b	10320.82	30491.97	2.954414	0.01691	Positive
225	10013.57	27544.15	2.750682	0.001924	Positive
180	10018.48	38037.4	3.796724	0.000357	Positive
135	10189.73	33837.79	3.320774	-0.38636	Negative

302

Direction	JF base shear(kN)	JF base shear at collapse (kN)	302 JF RSR	% differences	
90	10019.92	35736.01	3.566497	-0.09358	Negative
45	19908.86	35932.58	1.804854	0.274811	Positive
0	8843.37	39495.45	4.466109	2.796003	Positive
315	10012.86	29354.66	2.931696	-0.15102	Negative
270a	10319.76	30491.61	2.954682	0.018526	Positive
270b	10320.62	32622.23	3.160879	7.006463	Positive
225	10013.88	27543.87	2.750569	-0.00219	Negative
180	10018.51	38040.91	3.797063	0.009286	Positive
135	10189.79	33969.52	3.333682	0.000844	Positive

303

Direction	JF base shear(kN)	JF base shear at collapse (kN)	303 JF RSR	% differences	
90	10012.48	35777.62	3.573303	0.097073	Positive
45	19909.26	35894.83	1.802921	0.167452	Positive
0	8842	38047	4.302986	-0.95858	Negative
315	10014.68	29354.69	2.931166	-0.16906	Negative
270a	10318.87	30483.18	2.95412	-0.0005	Negative
270b	10321.64	30490.96	2.954081	0.005651	Positive
225	10014.18	28253.8	2.821379	2.572135	Positive
180	10018.5	38041.82	3.797157	0.011778	Positive
135	10189.82	33812.97	3.318309	-0.46031	Negative

304

Direction	JF base shear(kN)	JF base shear at collapse (kN)	304 JF RSR	% differences	
90	10020.05	35776.65	3.570506	0.018739	Positive
45	19909.25	33773.91	1.696393	-5.7511	Negative
0	8841.86	49682.27	5.618984	29.33163	Positive
315	10014.64	29354.84	2.931193	-0.16815	Negative
270a	10319.15	30488.9	2.954594	0.015549	Positive
270b	10321.55	30486.04	2.95363	-0.00961	Negative
225	10013.91	27544.05	2.750579	-0.00183	Negative
180	10018.61	38935.66	3.886334	2.360555	Positive
135	10189.91	33843.04	3.321231	-0.37267	Negative

(BF)Buitrago et al joint flexibility equations method:

Joint 201

Direction	BF base shear(kN)	BF base shear at collapse (kN)	201 BF RSR	% differences	
90	10019.94	33608.46	3.354158	-6.04171	Negative
45	19909.12	35903.62	1.803376	0.192685	Positive
0	8841.9	37864.24	4.282365	-1.43321	Negative
315	10012.53	29354.57	2.931783	-0.14803	Negative
270a	10319.2	30485.23	2.954224	0.003025	Positive
270b	10320.45	30491	2.954425	0.017314	Positive
225	10013.64	27543.64	2.750612	-0.00063	Negative
180	10018.49	38037.71	3.796751	0.001073	Positive
135	10189.84	33968.85	3.3336	-0.00162	Negative

Joint 202

Direction	BF base shear(kN)	BF base shear at collapse (kN)	202 BF RSR	% differences	
90	10019.71	35714.29	3.564404	-0.15221	Negative
45	19909.1	35897.41	1.803065	0.175456	Positive
0	8841.82	37962.35	4.2935	-1.17692	Negative
315	10012.54	29354.62	2.931786	-0.14796	Negative
270a	10319.1	30484.94	2.954225	0.003043	Positive
270b	10320.48	30491.27	2.954443	0.017908	Positive
225	10013.64	27543.85	2.750633	0.000136	Positive
180	10018.49	38037.07	3.796687	-0.00061	Negative
135	10189.77	33846.99	3.321664	-0.35967	Negative

203

Direction	BF base shear(kN)	BF base shear at collapse (kN)	203 BF RSR	% differences	
90	10019.86	35773.66	3.570275	0.012276	Positive
45	19909.1	35895.81	1.802985	0.170991	Positive
0	8841.88	39797.48	4.50102	3.599561	Positive
315	10012.52	29354.61	2.93179	-0.1478	Negative
270a	10319.14	32460.06	3.145617	6.48183	Positive
270b	10320.39	30491.27	2.954469	0.018781	Positive
225	10013.65	27543.83	2.750628	-3.6E-05	Negative
180	10018.49	38037.41	3.796721	0.000284	Positive
135	10189.84	33880.07	3.324887	-0.26297	Negative

204

Direction	BF base shear(kN)	BF base shear at collapse (kN)	204 BF RSR	% differences	
90	10019.96	35769.7	3.569845	0.000207	Positive
45	19909.11	35893.88	1.802887	0.165555	Positive
0	8841.82	37858.22	4.281723	-1.44799	Negative
315	10012.48	29354.56	2.931797	-0.14757	Negative
270a	10319.15	30484.97	2.954213	0.002657	Positive
270b	10320.52	30490.95	2.954401	0.016471	Positive
225	10013.65	27543.84	2.750629	0	Negative
180	10018.49	38037.32	3.796712	4.72E-05	Positive
135	10189.82	33887.53	3.325626	-0.24082	Negative

206

Direction	BF base shear(kN)	BF base shear at collapse (kN)	206 BF RSR	% differences	
90	10018.38	35729.98	3.566443	-0.09508	Negative
45	19908.43	35904.28	1.803471	0.198	Positive
0	8842.29	39830.58	4.504555	3.680919	Positive
315	10013.77	34764.5	3.47167	18.23964	Positive
270a	10318.71	32494.17	3.149054	6.598166	Positive
270b	10320.8	32572.07	3.155964	6.840066	Positive
225	10013.39	27544.56	2.750773	0.005211	Positive
180	10018.34	38037.88	3.796825	0.003017	Positive
135	10190.1	33819.85	3.318893	-0.44279	Negative

208

Direction	BF base shear(kN)	BF base shear at collapse (kN)	208 BF RSR	% differences	
90	10018.59	35760.34	3.569398	-0.01229	Negative
45	19909.79	35938.71	1.805077	0.287233	Positive
0	8841.67	39791.16	4.500412	3.58557	Positive
315	10014.29	29302.88	2.926107	-0.34138	Negative
270a	10320.4	32493.84	3.148506	6.579628	Positive
270b	10321.42	30496.11	2.954643	0.024674	Positive
225	10014.41	27544.12	2.750449	-0.00657	Negative
180	10018.44	38036.01	3.7966	-0.0029	Negative
135	10189.67	33968.95	3.333665	0.000344	Positive

301

Direction	BF base shear(kN)	BF base shear at collapse (kN)	301 BF RSR	% differences	
90	10019.8	35709.84	3.563927	-0.16555	Negative
45	19908.89	33946.4	1.705088	-5.26804	Negative
0	8842.43	36896.88	4.172708	-3.95716	Negative
315	10013.02	29353.99	2.931582	-0.15489	Negative
270a	10319.06	30479.07	2.953667	-0.01583	Negative
270b	10320.91	32422.96	3.141483	6.349835	Positive
225	10013.52	27544.54	2.750735	0.00384	Positive
180	10018.51	38037.57	3.796729	0.000505	Positive
135	10190.03	33839.02	3.320797	-0.38567	Negative

302

Direction	BF base shear(kN)	BF base shear at collapse (kN)	302 BF RSR	% differences	
90	10019.94	35740.79	3.566966	-0.08042	Negative
45	19908.89	33946.4	1.705088	-5.26804	Negative
0	8843.95	39822.55	4.502801	3.640559	Positive
315	10013.13	29279.85	2.924146	-0.40817	Negative
270a	10319.9	32398.59	3.139429	6.272357	Positive
270b	10320.65	32626.79	3.161312	7.021109	Positive
225	10013.84	27539.8	2.750174	-0.01656	Negative
180	10018.53	38039.65	3.796929	0.005774	Positive
135	10189.76	33969.78	3.333717	0.001904	Positive

303

Direction	BF base shear(kN)	BF base shear at collapse (kN)	303 BF RSR	% differences	
90	10019.91	35778.77	3.570768	0.026063	Positive
45	19909.68	35889.98	1.80264	0.151805	Positive
0	8841.97	38134.62	4.31291	-0.73015	Negative
315	10014.62	29317.65	2.927485	-0.29443	Negative
270a	10315.96	39485.08	3.827572	29.5666	Positive
270b	10321.7	30490.51	2.95402	0.003594	Positive
225	10014.33	27543.64	2.750423	-0.00752	Negative
180	10018.51	38041.88	3.797159	0.011836	Positive
135	10189.81	33297.15	3.267691	-1.9787	Negative

304

Direction	BF base shear(kN)	BF base shear at collapse (kN)	304 BF RSR	% differences	
90	10020.07	35775.72	3.570406	0.015939	Positive
45	19909.32	35898.48	1.803099	0.177335	Positive
0	8841.78	37666.09	4.260012	-1.9477	Negative
315	10014.56	29354.98	2.93123	-0.16688	Negative
270a	10318.55	30487.2	2.954601	0.015788	Positive
270b	10321.55	30486.17	2.953643	-0.00919	Negative
225	10014.01	27544.16	2.750562	-0.00243	Negative
180	10018.66	38034.61	3.796377	-0.00877	Negative
135	10189.94	33968.8	3.333562	-0.00275	Negative

APPENDIX B

Guide to include local joint flexibility in SACS model and collapse input.

100 years environmental loads for 45º loading direction in SACS' Datagen:

```
LOADCN   63
LOADLB   63 STORM WAVE & CUR DIR 45°
CURR
CURR          0.000    0.000   45.000          0.700        US LN         AWP
CURR          9.460    0.550   45.000
CURR         47.300    0.950   45.000
CURR         94.600    1.200   45.000
WIND
WIND D F     24.0             45.0
WAVE
WAVE0.95STOK 11.70 94.60 10.60         45.00       D   0.00   5.00   72MM10 1 1
```

Introducing local joint flexibility:

Edit in option from SACS' model file (SACINP.F9JT-A)

```
 *       6) Add New Riser Guard Model (21.9.07)                       *
 *                                                                    *
 **********************************************************************
OPTIONS       MN    PI   SDUC    4 4    DC   C     PTPTPTPTPT     PT        BF
```

Introducing BF local joint flexibility. Same goes to JF

Edit in collapse input: to include BF local joint flexibility

C:\Users\Asus\Desktop\new f9\bf\all first layer primary\clpinp.F91

```
CLPOPT      20   8 20          CN    LBBFPP              SF2U     0.10.001 0.01       0.002
CLPOP2    0.25    20.0
CLPRPT P1R1M1          SMMSPW

JFSEL I   201   202   203   204
LDSEQ AAA              DL    5             1.LL01    5            1.0ST01   25           5.
GRPELA              1A1 1A2 1A3 1A4 1A6 1A7 1A8 1A9 1AH 1B1 1B2 1B3 1B5 1B6 1B7
GRPELA              2A4 3A3 3A4 3A6 3A7 3A8 3A9 4A1 4A2 4A3 4A4 4A5 4A6 4A7 4A8
GRPELA              4A9 5A5 BL1 BL2 BL3 BL4 BL5 BL6 BL7 BSS BST C1A C1C C1G C1L
GRPELA              C2D C3G C4G C5G CON CRB CRC CRA CRN CS1 CT1 D1A D1B D1C D1G
GRPELA              D1H D1I D1J D1K D1L D1M D1P D1R D1S D2A D2B D2G DL1 DL2 DL3
GRPELA              DL4 FAA FAB FAC FAD FAE FAG JST JT1 JT2 P1B P1C P1D P2A P2B
GRPELA              P2C P2D P2E P2F P2G P2F P2J P3D P4A P4B P4C P4E P4G P4H P4I
GRPELA              P4J P4L P4M P4N P5G P5H P6G P6J RG1 RG2 RG3 RGS RGT RS1 RS2
GRPELA              RS3 RS4 RT1 RT2 RT3 RT4 T11 T13 T14 T22 TG5 TH5 TV5 TV6
END
```

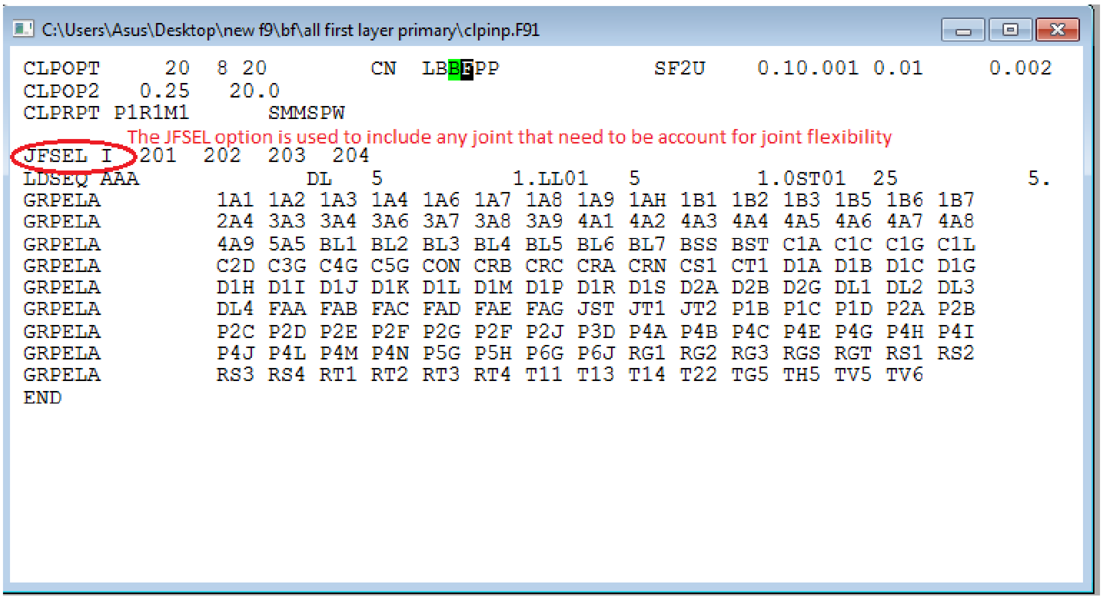
Set BF here for BF local joint flexibility option, same goes to JF

COLLAPSE Options

Max.Iterations Per Load Incmnt			20
Number of Member Segments			8
Max. No. of Member Iterations			20
☐ Treat skipped members as plastic			☑ Continue if Max. Iterations Exceeded
Include Local Buckling Effects	◉ YES	○ NO	
Local Buckling Method			2U
Joint Flexibility Effects	○ None	○ JF	◉ BF
☑ Include Pile Plasticity			
Joint Strength Check Option			None
☐ All Members Elastic			☑ Create model file w/ final defl. shape
Deflection Tolerance (CM)			0.1
Rotation Tolerance (RAD)			0.001
Member Deflection Tolerance (CM)			0.01
Collapse Deflection (CM)			0
Strain Hardening Ratio			0.002

< Prev | Next > | OK | Cancel | Help

To include local joint flexibility for joints 201,202,203, 204



```
C:\Users\Asus\Desktop\new f9\bf\all first layer primary\clpinp.F91
CLPOPT     20   8  20          CN   LBBEPP          SF2U      0.10.001 0.01       0.002
CLPOP2    0.25    20.0
CLPRPT P1R1M1        SMMSPW
JFSEL I    201   202   203   204
LDSEQ AAA              DL    5            1.LL01    5            1.0ST01   25          5.
GRPELA         1A1 1A2 1A3 1A4 1A6 1A7 1A8 1A9 1AH 1B1 1B2 1B3 1B5 1B6 1B7
GRPELA         2A4 3A3 3A4 3A6 3A7 3A8 3A9 4A1 4A2 4A3 4A4 4A5 4A6 4A7 4A8
GRPELA         4A9 5A5 BL1 BL2 BL3 BL4 BL5 BL6 BL7 BSS BST C1A C1C C1G C1L
GRPELA         C2D C3G C4G C5G CON CRB CRC CRA CRN CS1 CT1 D1A D1B D1C D1G
GRPELA         D1H D1I D1J D1K D1L D1M D1P D1R D1S D2A D2B D2G DL1 DL2 DL3
GRPELA         DL4 FAA FAB FAC FAD FAE FAG JST JT1 JT2 P1B P1C P1D P2A P2B
GRPELA         P2C P2D P2E P2F P2G P2F P2J P3D P4A P4B P4C P4E P4G P4H P4I
GRPELA         P4J P4L P4M P4N P5G P5H P6G P6J RG1 RG2 RG3 RGS RGT RS1 RS2
GRPELA         RS3 RS4 RT1 RT2 RT3 RT4 T11 T13 T14 T22 TG5 TH5 TV5 TV6
END
```

The JFSEL option is used to include any joint that need to be account for joint flexibility