EFFECT OF LOCAL JOINT FLEXIBILITY (LJF) IN STRUCTURAL ASSESSMENT OF AGEING JACKET OFFSHORE PLATFORM

by

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18878

Dissertation submitted in partial fulfilment of
The requirements for the
Degree of Engineering (Hons)
(Civil)

SEPTEMBER 2017

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL)

Approved by,

____
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TRONOH, PERAK
September 2017

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.

MUHAMMAD NUR IMAN BIN AZHAR

Abstract

Many fixed steel offshore platforms installed around the globe has exceeded or is approaching the end of design life. In many operating areas, there is an attraction to continue using these ageing facilities dues to continued production or as an adjoining structure to facilitate a new field development or expansion. The structure of the Jacket Type Offshore Platform (JTOP) are mainly connection of tubular members. To justify the life extension of the fixed platforms, various integrity assessment techniques are often used. One of the major techniques used is based on the phenomenon of Local Joint Flexibility (LJF). Although LJF is well known in the offshore industry since the early 1980s, little proven data is available. A static structural analysis has been done using ANSYS software to study the flexibility of the offshore tubular joint in a rigid state. Deformation at the joint and stresses in the members of K -joint are investigated. The joint is assumed to be in flexible condition which is subjected to tension and compression to determine the deformation and stresses. The main objective of this paper is to study the deformation at the joint and stress in the members of a K- joint. The deformation and stresses are obtained from Finite Element (FE) method. Data from ANSYS will be compared with data from SACS software in order to determine the effect of Local Joint Flexibility (LJF) in structural assessment of ageing Jacket platform. As conclusion, LJF are more flexible and able to distribute a greater stress in the members.

ACKNOWLEDGEMENT

First and foremost, my utmost gratitude to my supervisor, Ir. Dr. Mohamed Mubarak Abdul Wahab whose sincerity and encouragement will never be forgotten. Besides his unselfish and unfailing support, he guided me the right way for my Final Year Project (FYP) without considering his own time. He had shared valuable insights in the relevance knowledge which is truly helped the progression and smoothness of this study. Besides, he always assists to provide solution and motivation to complete this study.

Not to forget, my grateful thanks also go to my former lecturer Dr. Montasir, Dr. Zahiraniza and Dr. Noor Amila for the lectures that provide so much information and exposure regarding oil and gas industry, designing Jacket offshore platform and pipeline. These topics are very informative and helpful in order to complete this study.

Furthermore, I also would like to thank you to industry people, Mr. Shamsul and Mr. Zahari which is from Sapura Energy and Group Technical Solutions (GTS) PETRONAS. The provided information about Local Joint Flexibility (LJF) was very informative and able to make the author get better understanding to complete this study.

Last but not least, I am also indebted to my family and friends which always provide motivational support and knowledge for me to never give up completing my Final Year Project.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the era of globalization, the oil and gas industry gives impact to the global economy by providing the most important natural resources and producing many products for various usage. Petroleum is one of the main resources for the oil and gas industry where most of the petroleum can be found below the seabed in the ocean. This can be proven by the increase in the distribution of offshore platforms since the past few decades. Since 1930s until the present day, majority of the offshore platforms installed around the world are using the type of platform which known as fixed offshore platform. However, it is found that many fixed platforms have exceeded or is approaching the end of design life and leads the industry to believe they are still well-operated. Therefore, the platforms need to undergo condition assessment in order to determine the ability for life extension.

1.2 Problem Statement

In most analyses, joints are assumed to be fully clamped (rigid condition) and their flexible deformability is not accounted for in assessment of Jacket Type Offshore Platforms (JTOP). However, there is always some flexibility in joints particularly when members undergo beyond elastic region. Since the forces are distributed among the tubular members, it is hypothesized that this leads to stress reduction in the members. Hence, the effect of Local Joint Flexibility (LJF) in stresses reduction in tubular members are to be studied. And this is believed to affect the performance of the JTOP.

1.3 Objective

In this study, the objectives that need to achieve are:

1) To determine how the Local Joint Flexibility (LJF) reduce the stresses in the members.
2) To determine how the LJF governs the deformation at the joint

1.4 Scope of Study

This study is mainly focus on Local Joint Flexibility (LJF) of Jacket Type Offshore Platforms (JTOP) which is a fixed structure offshore platform. The members of the joint are tubular connection and there is various type of connection. The study is focusing on modelling the K-joint and analyzing the joint to study the deformation, stresses in the members and nonlinear behavior. The results may be taking into account for condition assessment for ageing platform later. SACS and ANSYS software will be used in this study. Stresses in tubular members could be determined from existing data of JTOP by using SACS. Then, the data will be used in ANSYS for modelling and analyzing of K-joint.

CHAPTER 2

LITERATURE REVIEW

Jacket Type Offshore Platform (JTOP) structures consist of connected of tubular members and it is installed on seabed for exploration and production of petroleum from the ocean floor. The tubular members acting as base which supports the facilities on the JTOP above the elevation of wave. According to Satyanarayana et al, (2011), there are more than 7000 offshore platforms installed around the world. Typical JTOP is consist of a foundation piles, topsides (superstructure), structure of tubular members (substructure) as shown in Figure 1 below. The substructure of the JTOP extends from ocean floor until the above sea surface level.

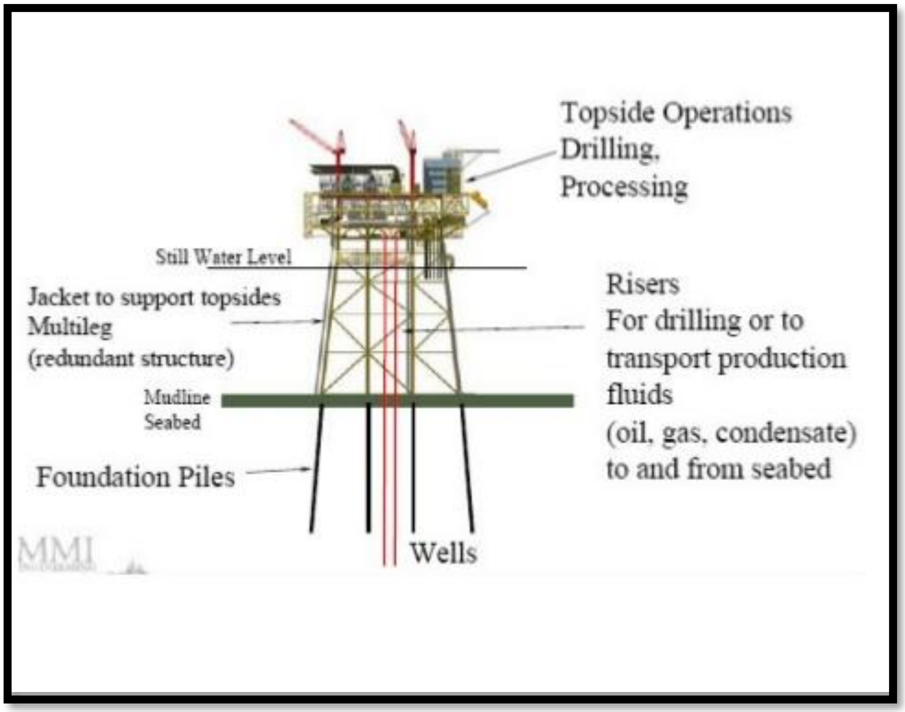


Figure 2.1: Components of JTOP

The tubular members are fabricated in one piece as a substructure on shore and transported to the sea by barge and installed on site by partial flooding. Satyanarayana et al, (2011) stated that the piles are driven through the main legs of the JTOP to fixed the structure to the sea floor and also acting as support for the deck and resist the lateral loadings such as wind, waves and current.

According to Mirtaheri et al, (2009), the tubular members are hollow section and it effectively produce buoyancy upon installation. Tubular members are designed to withstand the instrumental loads as well as environmental loads or forces such as wave, current, wind and earthquake. Moreover, these tubular members are high torsional strength, economical design and conveniently in welding of connections. Besides, the joint of these tubular members is designed as rigid joint but there is also some degree of flexibility occur at the joint when installed on site. (Khan et al, 2016).

The joint between tubular members is known as tubular connection. The main member referred as chord and the attached members are referred as braces. Typical connection of tubular members may consist of a few bracing members which are directly welded to the main members. The joint could be strengthened by thickening the member thickness. Usually, the external diameter of chord is larger than external diameter of brace. The joint without reinforcement known as an unstiffened joint (Satyanarayana et al, 2011).

Figure 2.2: Tubular Connection

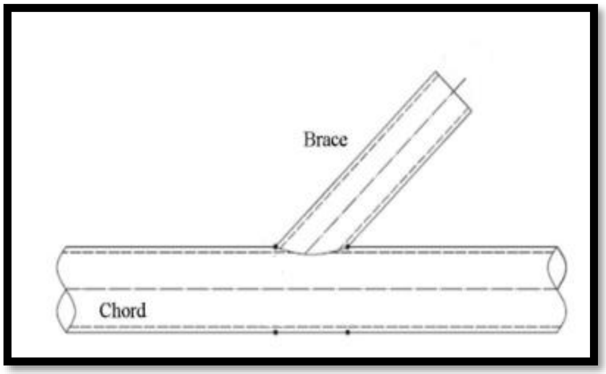


Figure 2.3: Brace and Chord of a joint

Satyanarayana et al, (2011) recommend that circular cross section of tubular members is the most suitable section compared to other types of cross sections. It is widely used in the oil and gas industry as the structure component of JTOP. This is because the ability of their drag characteristics to minimize wave forces on the structure. Furthermore, the closed cross section provides for the needed of buoyancy during installation of the platform in the ocean.

Khan et al, 2016 stated that Local Joint Flexibility (LJF) is one of the major techniques used in condition assessment to determine the life extension of a Jacket platform. In order to attempt the modelling of LJF, there would be computer software modelling and empirical formulas. Golafshani et al, (2013) studied on Local Joint Flexibility element for offshore platforms structures which solving the fundamental equations for shells. However, these formulation and matrices quite different from computer based program. Golafshani et al, (2013) stated that the equations for LJF element is based on fact for loading on a tubular joint (axial or flexural), chord wall would locally deform as it consistent the joint deformation which normally exist in the tubular connection (fixed). The LJF could be determine by local deformation which influenced by external loading in 3 directions which is axial loading, in-plane bending and out-plane bending. the formula as below:

$$LJF_{AX} = f_{AX} = \frac{\delta}{P} \qquad (1)$$

$$LJF_{IPB} = f_{IPB} = \frac{\varphi_I}{M_I} \qquad (2)$$

$$LJF_{OPB} = f_{OPB} = \frac{\varphi_O}{M_O} \qquad (3)$$

The parameters of ‘AX’, ‘IPB’, ‘OPB’, ‘δ’, ‘φ_1’ and ‘φ_0’ are axial loading, in-plane bending, out-plane bending, axial deformation, in-plane deformation and out-plane deformation.

The axial, in-plane bending and out-plane bending deformation are influenced by axial forces and bending moments. Golafshani et al, (2013) stated that as the chord length increases, the effect of LJF on overall behavior of tubular framed structure decreases. The diameter and chord length are two significant factors which dominate the effect of LJF on the structures. The parametric equation for Local Joint Flexibilities of equation (1, 2, 3) which corresponding to equation (4,5,6) are as below:

$$LJF_{AX} = \frac{1.95\gamma^{2.15}(1-\beta)^{1.3}\sin^{2.19}\varphi}{ED} \tag{4}$$

$$LJF_{OPB} = \frac{85.5\gamma^{2.2}\exp(-3.85\beta)\sin^{2.16}\varphi}{ED^3} \tag{5}$$

$$LJF_{IPB} = \frac{134\gamma^{1.73}\exp(-4.52\beta)\sin^{1.22}\varphi}{ED^3} \tag{6}$$

Whereby, $\beta = d/D$ and $\gamma = D/2T$

From the parametric equation, ‘d’, ‘D’, ‘T’, ‘E’ and ‘φ’ are brace diameter, chord diameter, chord thickness, elastic modulus and chord-brace intersection angles respectively. The parameters of K-joint could be refer to Figure 4 which also explained the direction of in-plane and out-plane bending moment, Crown Toe, Crown Heel and Saddle.

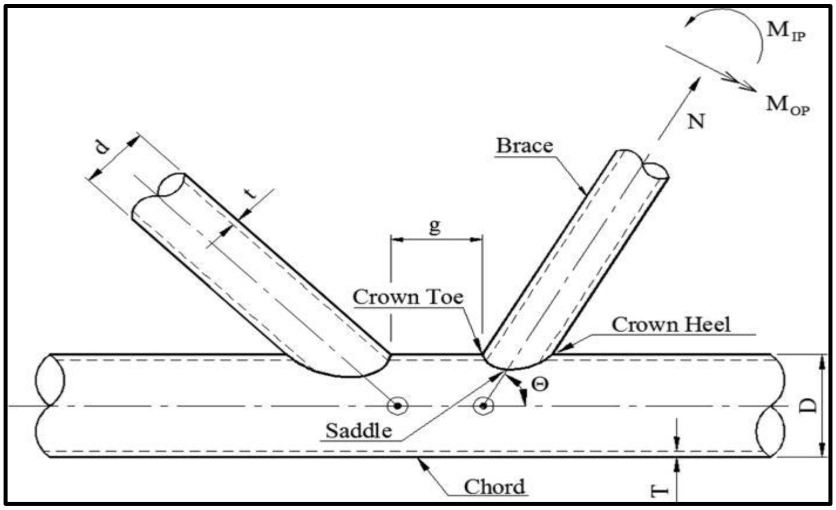


Figure 2.4: Parameters of Local Joint Flexibility (LJF)

Mirtaheri et al, (2009) has conducted research on the deformation of tubular joints where membrane-bending theory is applied. Large local deformations may occur when large force applied on the joints increase progressively which may cause nonlinear behavior at the joint. When any point at the joint experience yield, it loses the load carrying capacity and transfers induced stress to neighboring regions so that the joint will be able to transfer the forces/load. From the study, Mirtaheri et al, (2009) was using ANSYS software to carry out the Finite Element (FE) as it has capability and suitable for modeling the highly nonlinear shells having large deformation capability. Furthermore, Asgarian et al, (2014) conducted study on multi-brace joints which assumed the chord circular cross section to be negligible and the joints to be in rigid condition in their studies. Local Flexibilities matrices developed in the study and the gap between intersection of two braces is taken into account. There are a few important parameters for the LJF equations proposed by Asgaraian et al (2014) namely, θ_1, θ_2, γ, β_1, β_2, and ζ. The denotes are as below:

$\gamma = R_c/t_c$
$\beta_1 = R_{b1}/R_c$
$\beta_2 = R_{b2}/R_c$
$\zeta = g/R_c$

Whereby, Rc = Radius of Chord
t_c = Thickness of Chord
R_{b1} = Radius of Brace 1
R_{b2} = Radius of Brace 2
g = Gap between the two braces

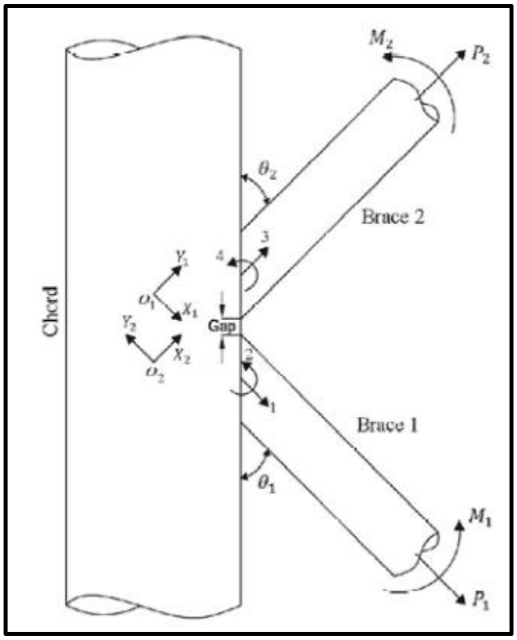


Figure 2.5: Definition of local coordinate system (Asgarian. B et al, 2014)

Asgarian et al (2014) also stated that at least 5.08 cm is the gap size recommended by American Petroleum Institute (API). For modeling, rigid plates are placed at the end of each braces to allow loads applied along the degrees of freedom. The design of chord length assumed as $12R_c$ to prevent the effect of boundary conditions of chord's end on deformation. The Finite Element (FE) is conducted using ANSYS by Asgarian et al (2014) and the analysis is performed with various of loading cases.

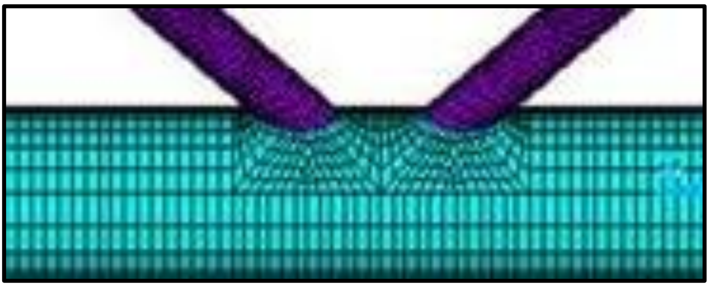


Figure 2.6: Meshing of K-joint (Finite Element)

The method for stress distribution in the tubular members is **Von Mises Stress** to determine the onset of failure in ductile materials. According to Satyanarayana et al,

(2011) the yield stress, σ_y of the material should be more than Von Mises stress, σ_{vm} as the failure criterion. In other meaning, $\sigma_{vm} \leq \sigma_y$. The Von Mises stress σ_{vm} is given by

$$\sigma_{VM} = \sqrt{I_1^2 - 3I_2} \tag{7}$$

Whereby I_1 and I_2 are the first two variants of the stress tensor and the stress of I_1 and I_2 are determined by

$$I_1 = \sigma_x + \sigma_y + \sigma_z \tag{8}$$

$$I_2 = (\sigma_x \sigma_y) + (\sigma_y \sigma_x) + (\sigma_z \sigma_x) - \tau^2_{yz} - \tau^2_{xz} - \tau^2_{xy} \tag{9}$$

As the term of principal stress, σ_1, σ_2 and σ_3, the two variants can be determine as given below

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 \tag{10}$$

$$I_2 = (\sigma_1 \sigma_2) + (\sigma_2 \sigma_3) + (\sigma_1 \sigma_3) \tag{11}$$

Mirtaheri et al, (2009) performed analysis on nonlinear push-over static which obtain the moment-rotation relationship of different types of angle intersection for Y-joint. At the beginning, axial loads are influenced in the struts to represent the axial loads which existed in the tubular members of offshore structure. Then, lateral progressively-increasing rotation (displacement control approach) is applied to represent as external rotations. From the result, as the initial load moves from compression towards tension, the capacity of the connection is increased vice versa. Hence, it shows that the effect of stress-stiffening in struts on the behavior and capacity of joints which basically states the tensile axial load strengthens the strut as well as its joint.

Chapter 3

METHODOLOGY

This chapter will describe the method to be used in the study/research to obtain the information, carry out analysis and planning (key milestone). The method for this study will be performing three type of analysis which is In – Place Analysis using SACS, Static Structural Analysis using ANSYS and Collapse Analysis using SACS. The type of platform chosen is the Jacket Type Offshore Platform (JTOP) as shown in Figure 3.1. The study will be focusing on the K- joint as shown in Figure 3.2. The selected K – joint is based on the consideration for the assignment of forces and support in ANSYS.

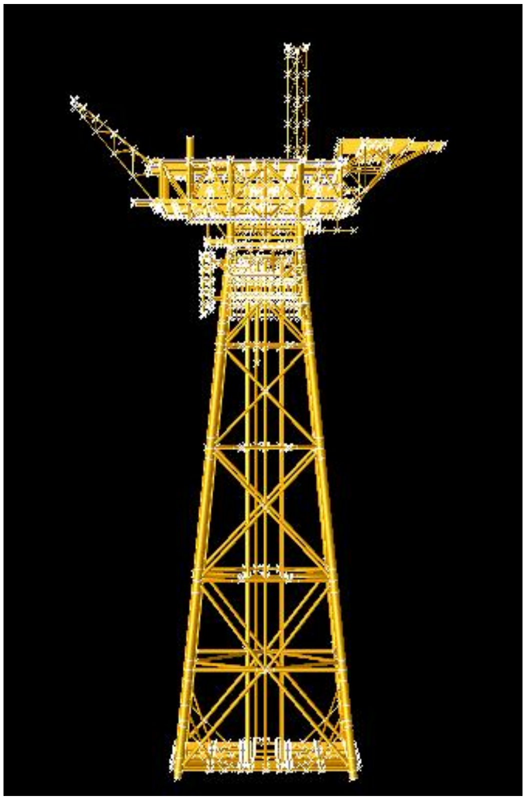


Figure 3.1: Jacket Type Offshore Platform model in SACS

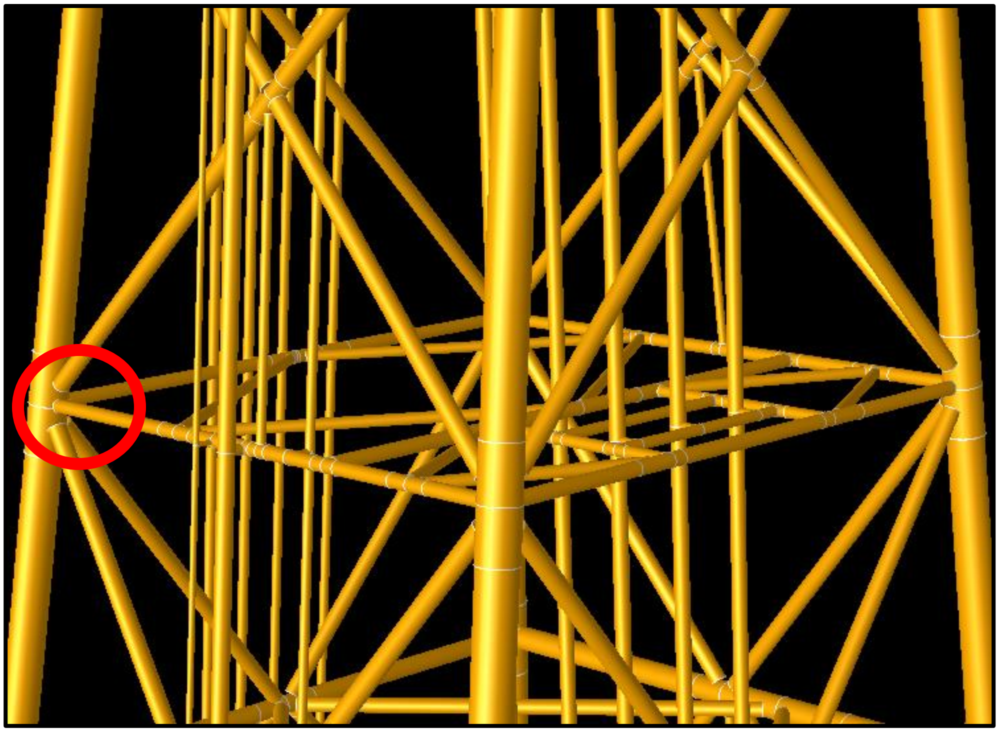
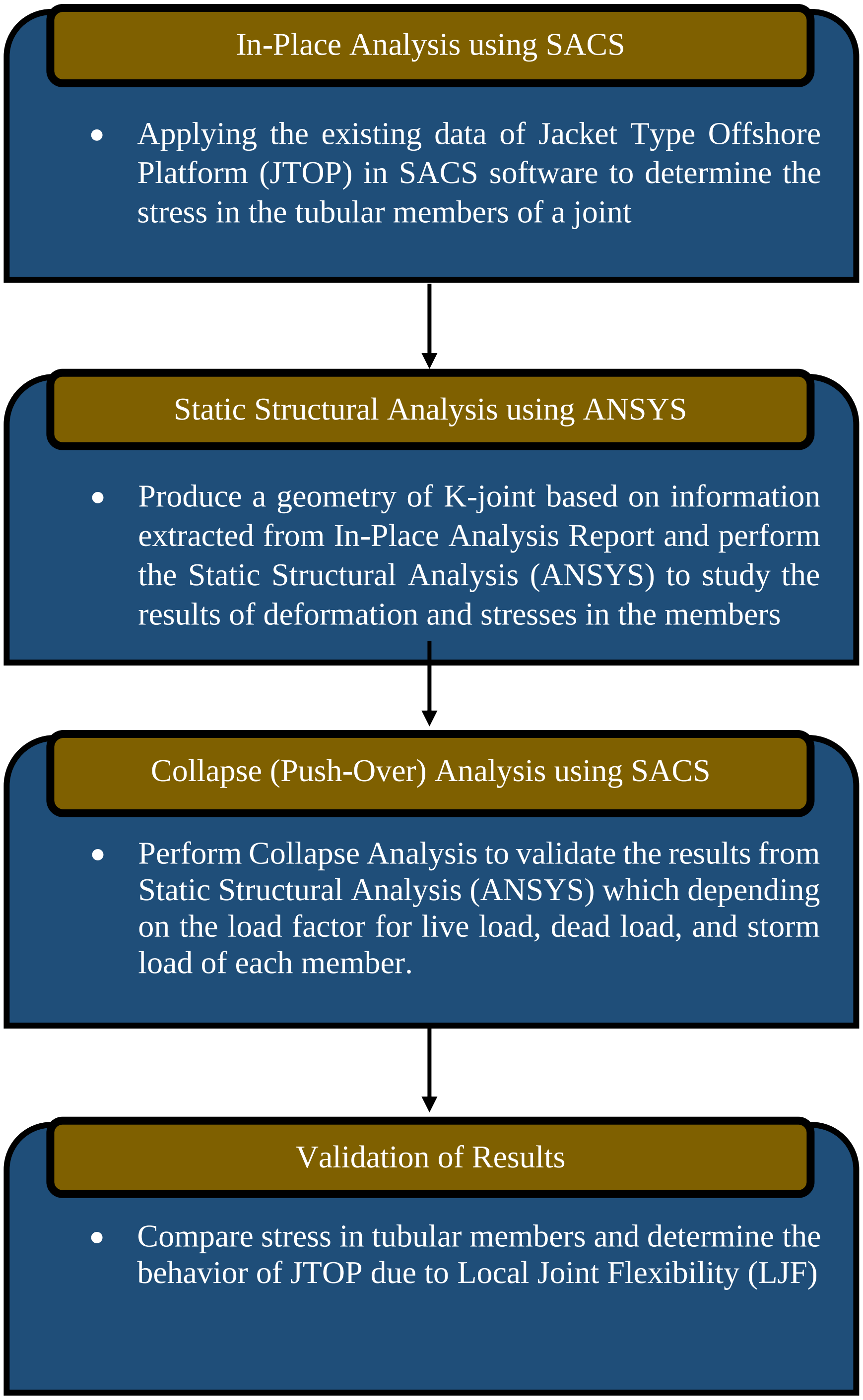


Figure 3.2: Joint of tubular members of JTOP (in the circle)

As looking into specific component of Jacket Type Offshore Platform (JTOP) which is the Local Joint Flexibility (LJF) and the study will focus on K-joint. In order to perform static structural analysis of the joint, ANSYS Software will be used in the study as the capability of its for modelling and analyzing. ANSYS is an engineering software which is pioneering the development and application of simulation methods to solve challenging product engineering problem. By using ANSYS, the analysis for Finite Element (FE), stress distribution and deformation could be carry out to design the joint and see the results of behavior of offshore structure. Furthermore, SACS 5.7 V8i is also being used in the study to determine the stress of the tubular members. In order to determine the stress, In-place analysis will be conducted using SACS which later will be contribute to the design of the joint in ANSYS. Therefore, three software are involved in the study as the AutoCAD for geometric design, SACS for In-place analysis and ANSYS for modelling and analyzing the joint which looking more into deformation of the joint while applying loads and all necessary condition. At the end, the stress distribution in SACS will be compared with the stress distribution in the ANSYS and also determine the deformation at the joints.

3.1 Flowchart



In-Place Analysis using SACS

- Applying the existing data of Jacket Type Offshore Platform (JTOP) in SACS software to determine the stress in the tubular members of a joint

Static Structural Analysis using ANSYS

- Produce a geometry of K-joint based on information extracted from In-Place Analysis Report and perform the Static Structural Analysis (ANSYS) to study the results of deformation and stresses in the members

Collapse (Push-Over) Analysis using SACS

- Perform Collapse Analysis to validate the results from Static Structural Analysis (ANSYS) which depending on the load factor for live load, dead load, and storm load of each member.

Validation of Results

- Compare stress in tubular members and determine the behavior of JTOP due to Local Joint Flexibility (LJF)

Figure 3.3: Summary of methodology.

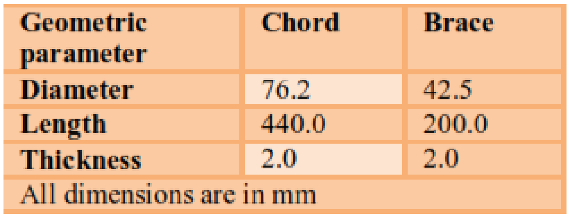
3.2 In-Place Analysis (SACS)

By using the data of existing platform in Sarawak, the Jacket Type Offshore Platform is 4-legged structure and the water depth is 94.8 meters. Dimension of selected K- joint such as outer diameter, thickness and length of member are obtained from In – Place Analysis Report in order to model a geometry of K -joint using AutoCAD. Furthermore, internal loads on each member of the K- joint also identified from the report as to be assigned as input forces for Static Structural Analysis in ANSYS. However, the results to be obtained from In – Place Analysis are the stresses in the member and deflection at the joint (selected K – joint). The platform undergoes In – Place Analysis based on the load factor of 1.0 for each dead load, live load and storm load. However, In-Place Analysis Report also provide information not only based on load factor of 1.0, it also shows the critical load condition for each member of the platform.

3.3 Static Structural (ANSYS)

3.3.1 Modelling

Before performing the static structural analysis, the geometric of the joint is designed using AutoCAD software. 3D modelling is applied in the designed prior to be used in the ANSYS. The design parameters of the geometry would be based on research by Satyanarayana et al, (2011). Since the study would be focusing on K-joint, the intersection angles of the joint would be referred to research paper by Asgarian. B et al, (2014) which is 'Local Joint Flexibility equations for Y-T and K-type Tubular Joints'. This is because the paper presenting the LJF equations for K-joint.



Geometric parameter	Chord	Brace
Diameter	76.2	42.5
Length	440.0	200.0
Thickness	2.0	2.0
All dimensions are in mm		

Table 3.1: Dimension used by Satyanarayana et al, (2011)

3.3.2 Project Schematic

Once the 3D modelling completed in AutoCAD, the design must be import into the ANSYS software. In this study, the joint would be designed as rigid joint. The chosen analysis system is the ‘Static Structural’ to perform the analysis. The component of ANSYS work program to perform the analysis as below:

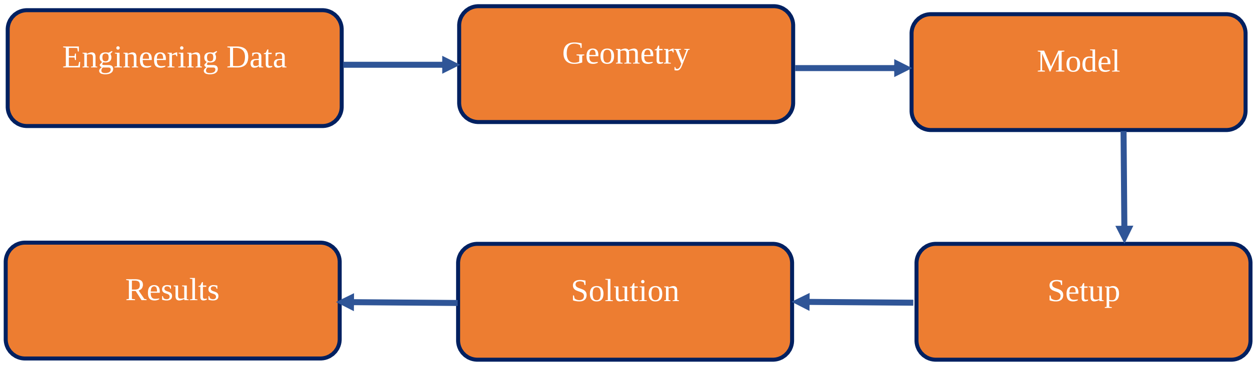


Figure 3.4: Schematic flow of modelling and analyzing the joint using ANSYS and AutoCAD.

3.3.3 Engineering Data

The component of ‘Engineering Data’ in ANSYS provides library of material which contain the types of material, material properties, physical properties and other type of condition to be applied on the material such as plasticity, life period, strength, damage, temperature condition and cohesive zone. Furthermore, it also helps to define and organize material properties, store material properties in a material property library which can be used in other projects, obtain material property data from existing material libraries, assign different material properties to different parts of a model and navigate the toolbox and data windows For example, as the stainless steel will be chosen in this study, there a few settings that can be setup for material properties such as density, tensile yield strength, compressive yield strength, tensile ultimate strength, and compressive ultimate strength of the material. All these properties will affect the result of LJF.

3.3.4 Geometry

For the geometric design, ‘Geometry’ component can be considered as complete because the 3D modelling has been import from AutoCAD software. However, the design of 3D modelling also could be carried out in the ‘Geometry’ component instead of design using AutoCAD. The interface of ‘Geometry’ in ANSYS is differ from AutoCAD.

3.3.5 Model

The ‘Model’ component is where the geometry could be assign as one element or can be more than one element. For example, in this study, the joint could be assign as more than one component which is brace and chord are different element. This will affect the results in terms of deformation and stress distribution after performing the analysis. Besides, this is also where the Finite Element (FE) method is applied whereby meshing is applied to the geometry. Meshing is consist of elements and nodes. The smaller the size of the meshing, more stress distribution can be determined and more accurate.

3.3.6 Setup

The ‘Setup’ component is where the type of support and loading cases applied to the geometry. applying the tension and compression on which faces chosen on the geometry. These will affect the stress distribution and deformation of the geometry (joint). Furthermore, the number of steps is required to view the animation of the geometry behavior after performing analysis.

3.3.7 Solution

The ‘Solution’ component is the selection of the type of results. The result that required could be the stress, strain, energy, deformation, fatigue and others but in this study, the results would be focus on the deformation and stress distribution of the joint (geometry).

3.3.8 Result

‘Result’ component is the output of ANSYS which provide the required information from the analysis. For stress distribution, animation is produced with respect to changing of time. There is also report file of the successful analysis which provide the results of the analysis.

3.4 Collapse Analysis (SACS)

Collapse analysis or known as Push - Over mode assessment offers and improved design concept over linear to non-linear which is elastic to plastic state. The load is applied to the structure incrementally. The nodal displacement and element forces are calculated for each load step and the stiffness matrix is updated. When the stress in a member reaches the yield stress, plasticity is introduced. The introduction of plasticity reduced the stiffness of the structure and additional loads due to subsequent load increments will be redistributed to adjacent members that have gone plastic. This phenomenon (progressive collapse of members) will continue until the structure as a whole will collapse or ‘Pushed-Over’. As mention above, the results of Collapse Analysis is used to validate the result from Static Structural Analysis (ANSYS) which the source of dimension and applied stress are based on In-Place Analysis. The result of Collapse Analysis will be focused on the load factor of 1.0 for each dead load, live load and storm load.

3.5 Gantt Chart

Below is the Gantt Chart for FYP 1

Project activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection	🟧													
Data findings & gathering		🟧	🟧	🟧										
Preparing Extended Proposal			🟧	🟧	🟧	🟧								
Submission of Extended Proposal						🟧								
Perform In-Place Analysis using SACS							🟧	🟧	🟧					
Modelling using AutoCAD and perform analysis using ANSYS								🟧	🟧					
Proposal Defense								🟧	🟧					
Project work continue									🟧	🟧	🟧	🟧		
Submission of Interim Draft Report													🟧	
Submission of Interim Report														🟧

Below is the Gantt Chart for FYP 2

Project activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Analyzing the result for the effect of Local Joint Flexibility (LJF)	🟧	🟧	🟧	🟧	🟧	🟧								
Submission of Progress Report							🟧							
Project work continue							🟧	🟧	🟧	🟧				
Pre-SEDEX										🟧				
Submission of Draft Final Report											🟧			
Submission of Dissertation Report (Soft bound)												🟧		
Submission of Technical Paper												🟧		
Viva													🟧	
Submission of Dissertation Report (Hard bound)														🟧

3.6 Key Milestone

Project activities	Week (FYP 1)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Data Finding & Gathering	■	■	■	■	■									
Preparation for Literature Review & Methodology			■	■	■	■								
Perform In-Place Analysis using SACS						■	■	■	■					
Extracting information from SACS analysis report							■	■	■					
Modelling using AutoCAD									■	■	■	■		
Perform Static Structural Analysis using ANSYS											■	■	■	■
Project activities	Week (FYP 2)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Perform Static Structural Analysis using ANSYS	■	■	■	■	■									
Preparation of Progress Report				■	■	■	■							
Comparing result from SACS and ANSYS						■	■	■						
Preparation of Pre-SEDEX								■	■					
Preparation of Technical Paper								■	■	■	■	■		
Preparation for Dissertation									■	■	■	■		
Preparation for Viva										■	■	■	■	■

CHAPTER 4

RESULTS AND DISCUSSION

4.1 In-Placed Analysis

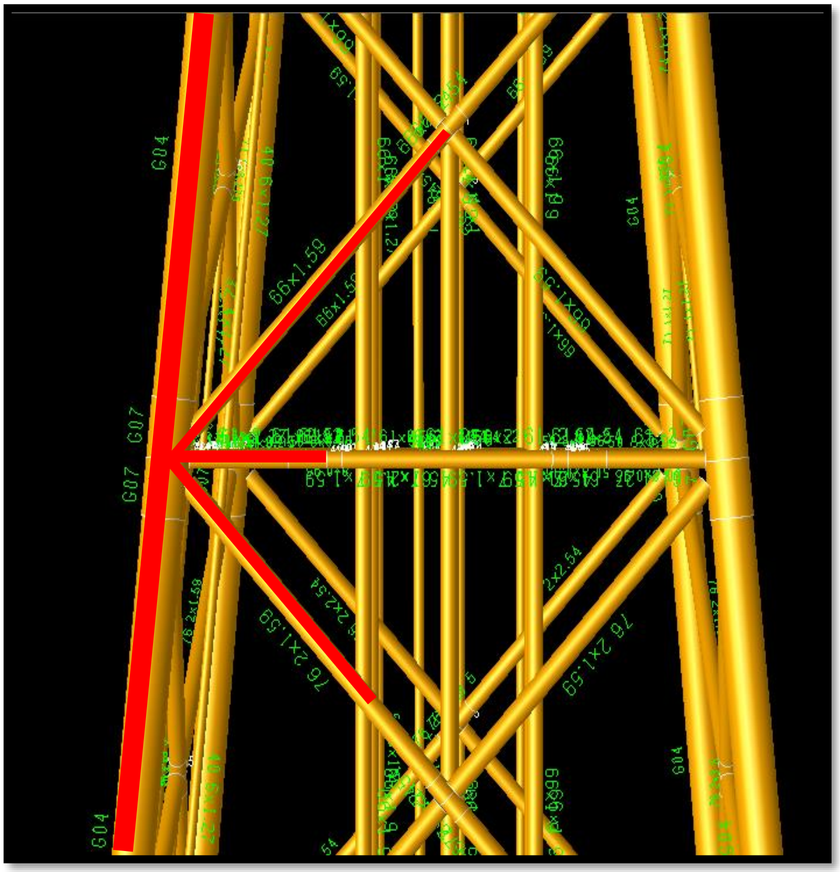


Figure 4.1: Selected K - joint (highlighted in red)

A joint will be considered as K-joint classification when the axial load in the brace should be balanced to within 10% by loads in other braces in the same plane and on the same side of the joint. Hence, the selected K – joint is shown in Figure 4.1.

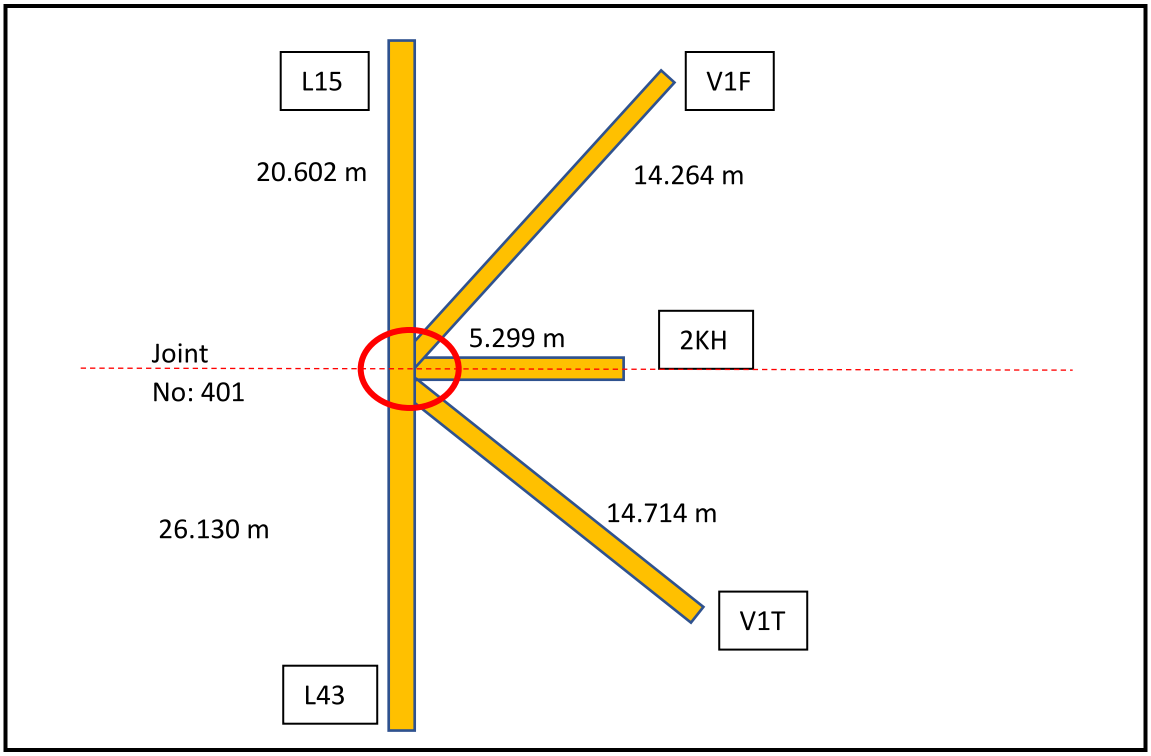


Figure 4.2: Summary of selected K- joint member group and length

4.1.1 Properties of Tubular Member

Table 4.1: Properties of tubular member

Member Label	Outside Diameter (cm)	Thickness (cm)	Yield stress (kN/cm^2)	Ring Spacing (mm)
L15 (Upper) – G02 L15 (Middle) – G04 L15 (Joint) – G07	170.00 164.00 171.00	5.000 2.000 5.500	34.000 34.500 34.000	1121.51 1680.21 1078.77
V1F	66.000	1.590	35.500	481.11
2KH	61.000	2.540	34.500	338.23
V1T	76.200	1.590	35.500	596.84
L43 (Joint) – G07 L43 (Middle) – G04 L43 (Below) – G02	171.00 164.00 170.00	5.500 2.000 5.000	34.000 34.500 34.000	1078.77 1680.21 1121.51

Table 4.1 shows the properties of each of the tubular member. The dimension of each tubular member is very important in order to remodel the geometry in AutoCAD software to be import in the ANSYS. The yield stress indicated the engineering properties

to be applied on the geometry in ANSYS. Besides, internal load of each member also provided by In – Place Analysis Report. By referring to Table 4.2, the internal loads are assigned on each member which resulting deflection at the joint and stresses in the members. Hence, the deflection at joint 401 and stresses in the members are the results to be obtained from the In – Place Analysis.

Table 4.2: Internal load of each member

Member	**Group**	**Load Case**	**Internal Load (kN)**		
			Axial	**Shear**	
				Y	**Z**
401 - 424	2KH	ST09	466.27	-3.2119	-1.3185
401 - 501	L15	ST09	-10082	11.588	-9.6105
301 - 401	L43	ST09	-10448	-14.448	12.440
401 – 461	V1F	ST09	1380.4	-13.312	-5.9725
357 – 401	V1T	ST09	-29.317	0.001018	-0.23766

4.1.2 Deflection

The selected K-joint labelled in SACS as ‘Joint 401’ whereby in the In-Place Analysis Report shows that the deflection due to load factor of 1.0 for dead load, live load, and storm load. The deflections at the joint are shown in Table 4.3 which produce by the assigned internal loads and the joint is deflecting to three different axes. However, the study will be focusing on the deflection on x-axis. This is because the K - joint in Static Structural Analysis (ANSYS) is bending towards the x-axis.

Table 4.3: Deflection at Joint 401

Joint No	Deflection (X), mm	Deflection (Y), mm	Deflection (Z), mm
401	-28.77	-34.56	-21.63

4.1.3 Stress

Furthermore, In – Place Analysis also provide the results of stresses in each member. The stresses in each member of In – Place Analysis are shown in Table 4.4 are produced due to internal load applied on the member as mention above (refer to Table 4.2).

Table 4.4: Element Stress Report

Member	Group	Load Case	Applied Stresses, N/mm^2		
			Axial	Shear	
				Y	Z
401 - 424	2KH	ST09	10.00	0.15	-0.35
401 - 501	L15	ST09	-20.55	0.03	0.30
301 - 401	L43	ST09	-20.19	0.04	0.16
401 – 461	V1F	ST09	10.32	0.91	0.64
357 – 401	V1T	ST09	-9.62	0.14	-0.13

Notes: * a) ST09 is whereby the load factor is 1.0 for dead load, live load and storm load.

4.2 Geometric Design

The selected K- joint has been remodel using AutoCAD based on the dimension that provided in In – Place Analysis Report such as outer diameter, thickness, length of the member and angle of intersection between chord and brcaes. The geometry has been design in form of 3-Dimensional (3D) and imported in the ANSYS to undergo Static Structural Analysis. However, the angle of intersection was determined by using Pythgoras Theorem as below:

$$\sin\theta = \frac{Opposite\ Length}{Hypotenuse\ Length} \qquad \cos\theta = \frac{Adjacent\ Length}{Hypotenuse\ Length}$$

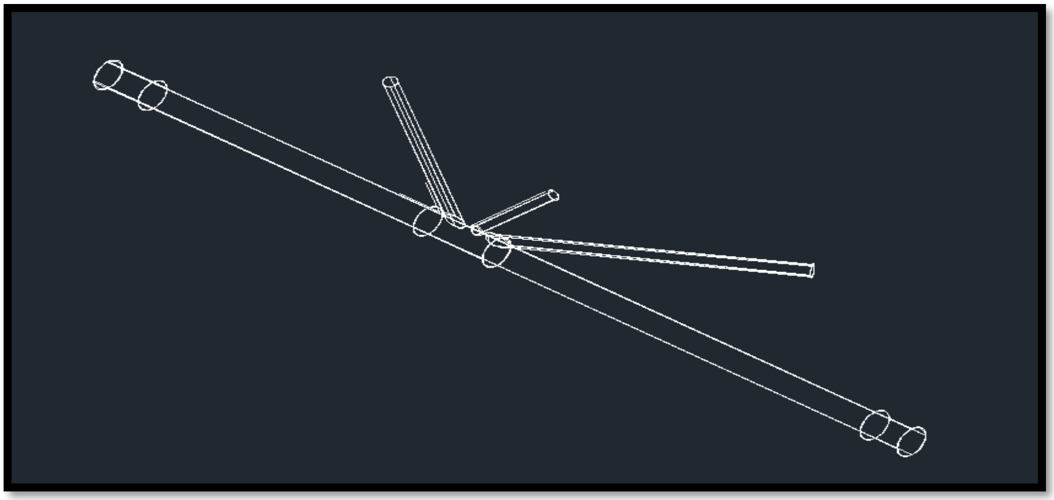


Figure 4.3: 2D wireframe of K- joint Geometry

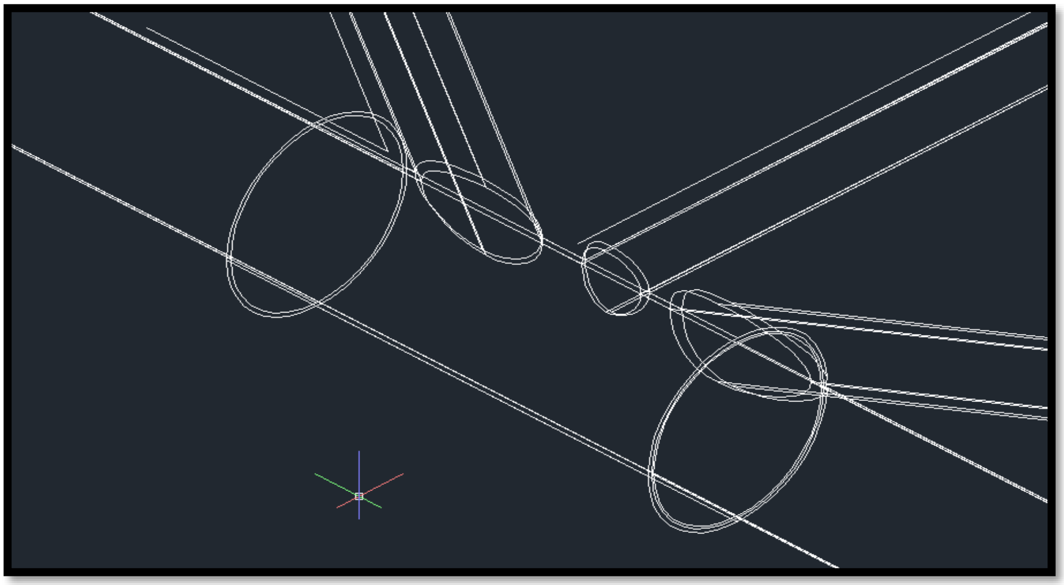


Figure 4.4: Tubular Connection at the K-joint

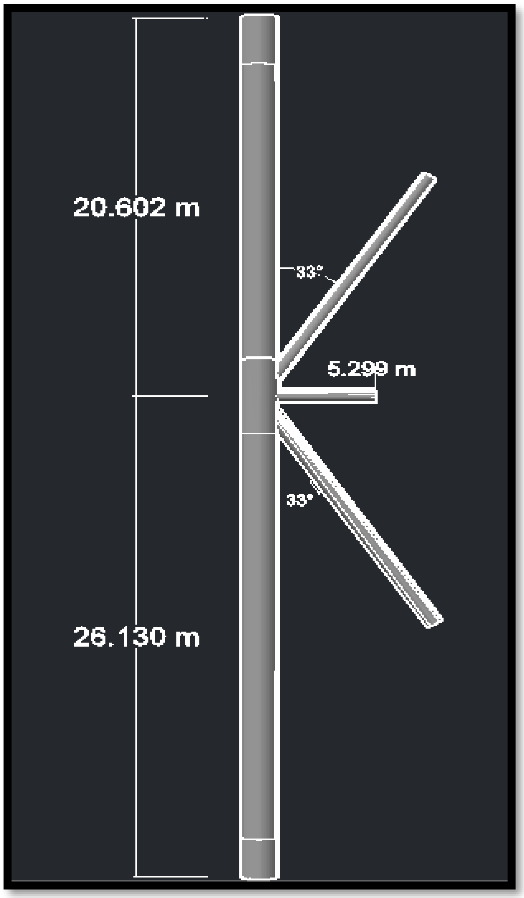


Figure 4.5: Dimension of the geometric design (3D)

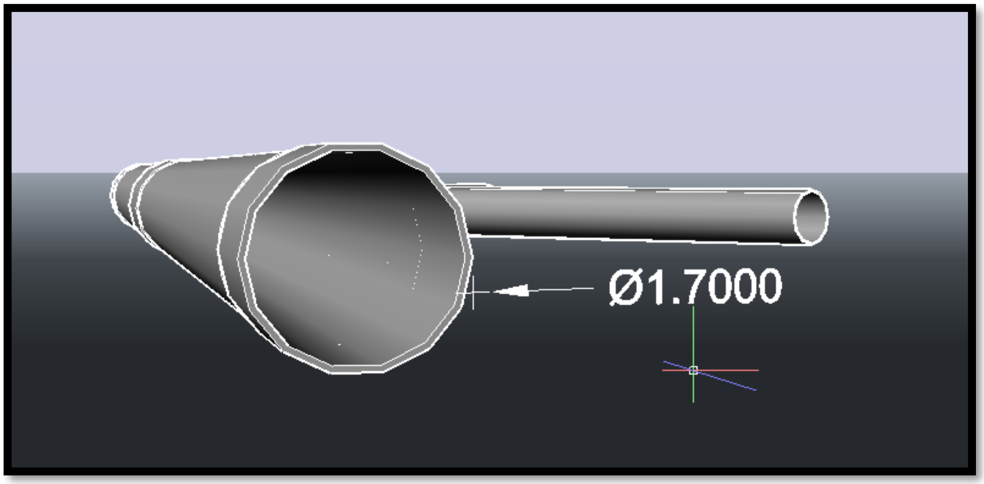
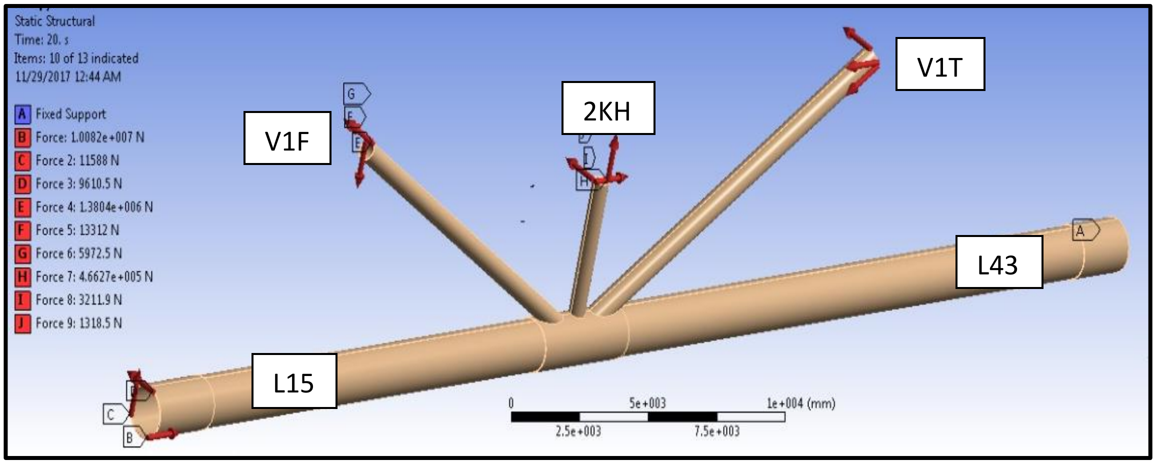


Figure 4.6: Outer diameter of chord member (L43)

4.3 Static Structural Analysis (ANSYS)

The results to be obtained from Static Structural Analysis are the deformation and stresses in the members. The forces applied on each member are axial force which acting normal to the member. Besides, shear force also has been applied on each member which due to y-axis and z-axis. This shows that the shear forces are acting tangentially towards the member either in compression or tension. The amount of forces applied on each member are based on Table 4.2. The applied forces on each member can be refer to Figure 4.7.



Static Structural
Time: 20. s
Items: 10 of 13 indicated
11/29/2017 12:44 AM

A Fixed Support
B Force: 1.0082e+007 N
C Force 2: 11588 N
D Force 3: 9610.5 N
E Force 4: 1.3804e+006 N
F Force 5: 13312 N
G Force 6: 5972.5 N
H Force 7: 4.6627e+005 N
I Force 8: 3211.9 N
J Force 9: 1318.5 N

Figure 4.7: Forces (axial and shear) and fixed support applied on the geometry

The force of axial tension, axial compression and shear (y-axis and z-axis) are applied on the braces (member V1T,V1F and 2KH) and chord (member L15). Fixed support is applied at the end of chord (member L43). The reason of applying fixed support at the end of member L43 is because the member is located at the bottom of the platform which having attached to the seabed. Piles are driven through member L43 make it a reason to known as fixed support. Axial compression is applied on the chord (member L15) and it is the highest axial compression load of the K-Joint.

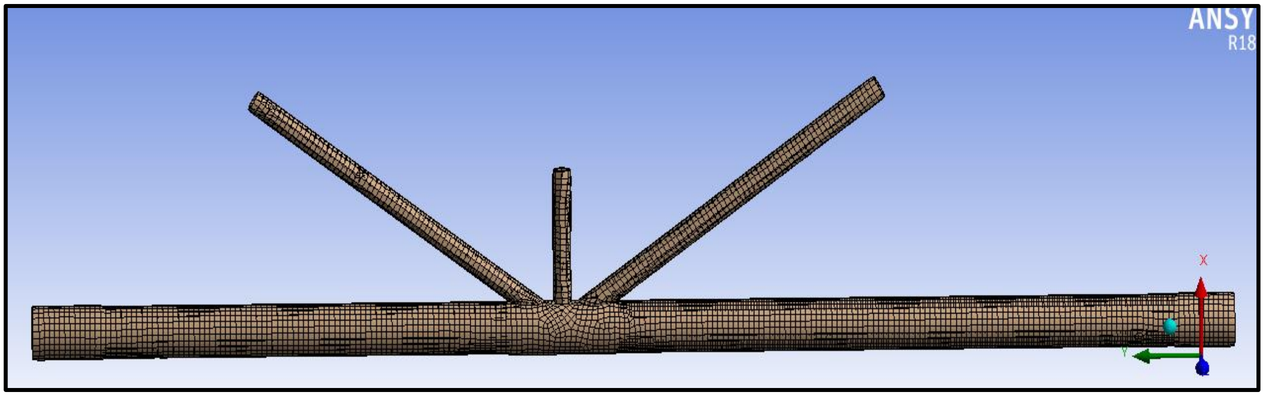


Figure 4.8: Meshing of the K - joint (FE)

The method of meshing used in ANSYS is body meshing as shown in Figure 4.8. The size of element is 0.2 m and the total number of nodes and elements are 14851 and 14879 respectively. The purpose of meshing is for the finite element process. Finite element method (FEM) is a numerical method for solving problems of engineering mathematical physics. In this study, FEM is used to obtain the value of stress and deformation on each node of the tubular members.

4.3.1 Equivalent Stress (Von-Mises)

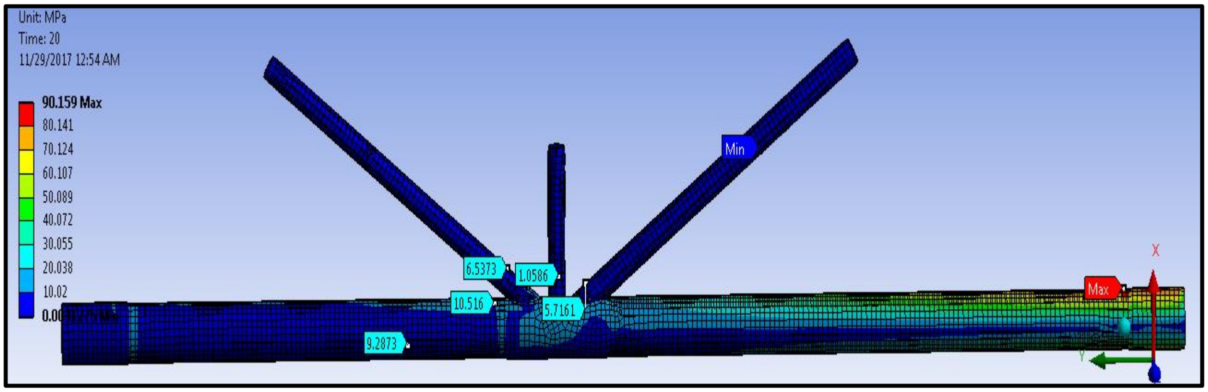


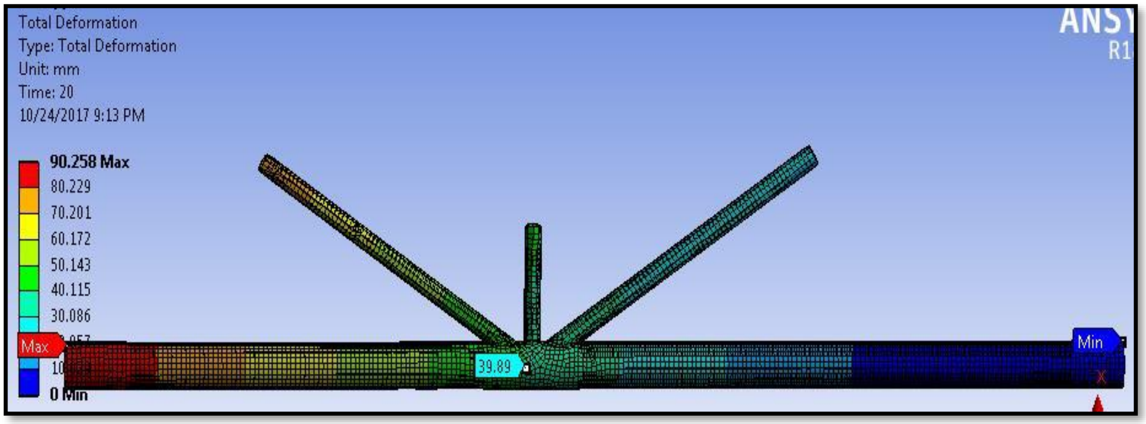
Figure 4.9: Stress (Von-Mises) distribution on the geometry

Maximum stress occurs at the end of member L43 which is 90.159 MPa. This is because of the assignment of fixed support and there is no other diagonal member to distribute the stress. However, the stress at the joint is 12.562 MPa which is higher compared to stress in braces member of V1F, 2KH, V1T and chord member of L15. This is because the stresses along the members are distributed through the joint which cause higher stress at the joint. Referring to Table 4.5, the value of stress of each member obtained from the Static Structural Analysis is the maximum stress. The maximum stress on member L15, V1F and 2KH are located near to the joint as shown in Figure 4.9. It shows that stresses are being transferred along the members and passes through the joint.

Table 4.5: Maximum stress on each member

Member	**Stress, σ (MPa)**
2KH	1.0586
L15	10.516
L43	65.376
V1F	6.5373
V1T	5.7161

4.3.2 Total Deformation



Total Deformation
Type: Total Deformation
Unit: mm
Time: 20
10/24/2017 9:13 PM

Figure 4.10: Deformation of K – joint tubular members

Referring to Figure 4.10, the maximum deformation occurs at the end of chord (member L15) which is 90.258 mm and deformation at joint is 39.89 mm. This is because the highest axial compression applied at the chord and the deformation shows the chord is bending towards x-axis plane. The minimum deformation which is 0 mm occur at the end of chord member L43. This is due to the assignment of fixed support which disable degrees of freedom. Table 7 shows the data of deformation of the K- joint for 20 seconds with 0.2 of interval.

Table 4.6: Maximum and Minimum of Equivalent Stress and Deformation of K -joint

Time (s)	Minimum (mm)	Maximum (mm)	Time (s)	Minimum (mm)	Maximum (mm)
0.2	0	0	8.4	1.01E-02	19.799
0.4	0	0	8.7	1.05E-02	20.602
0.7	0	0	9	1.09E-02	21.405
1	0	0	9.2	1.12E-02	21.94
1.2	2.73E-04	0.53512	9.4	1.15E-02	22.475
1.4	5.47E-04	1.0702	9.7	1.19E-02	23.278
1.7	9.57E-04	1.8729	10	1.23E-02	24.08
2	1.37E-03	2.6756	10.2	1.26E-02	24.615
2.2	1.64E-03	3.2107	10.4	1.29E-02	25.151
2.4	1.91E-03	3.7458	10.7	1.33E-02	25.953
2.7	2.32E-03	4.5485	11	1.37E-02	26.756
3	2.73E-03	5.3512	11.2	1.39E-02	27.291
3.2	3.01E-03	5.8863	11.4	1.42E-02	27.826
3.4	3.28E-03	6.4214	11.7	1.46E-02	28.629
3.7	3.69E-03	7.2241	12	1.50E-02	29.432
4	4.10E-03	8.0268	12.2	1.53E-02	29.967
4.2	4.38E-03	8.5619	12.4	1.56E-02	30.502
4.4	4.65E-03	9.097	12.7	1.60E-02	31.304
4.7	5.06E-03	9.8997	13	1.64E-02	32.107
5	5.47E-03	10.702	13.2	1.67E-02	32.642
5.2	5.74E-03	11.237	13.4	1.70E-02	33.177
5.4	6.02E-03	11.773	13.7	1.74E-02	33.98
5.7	6.43E-03	12.575	14	1.78E-02	34.783
6	6.84E-03	13.378	14.2	1.80E-02	35.318
6.2	7.11E-03	13.913	14.4	1.83E-02	35.853
6.4	7.38E-03	14.448	14.7	1.87E-02	36.656
6.7	7.79E-03	15.251	15	1.91E-02	37.458
7	8.20E-03	16.054	15.2	1.94E-02	37.993
7.2	8.48E-03	16.589	15.4	1.97E-02	38.529
7.4	8.75E-03	17.124	15.7	2.01E-02	39.331
7.7	9.16E-03	17.926	16	2.05E-02	40.134
8	9.57E-03	18.729	16.2	2.08E-02	40.669
8.2	9.84E-03	19.264	16.4	2.11E-02	41.204

Time (s)	Minimum (mm)	Maximum (mm)	Time (s)	Minimum (mm)	Maximum (mm)
16.7	2.15E-02	42.007	18.4	2.38E-02	46.555
17	2.19E-02	42.81	18.7	2.42E-02	47.358
17.2	2.22E-02	43.345	19	2.46E-02	48.161
17.4	2.24E-02	43.88	19.2	2.49E-02	48.696
17.7	2.28E-02	44.682	19.4	2.52E-02	49.231
18	2.32E-02	45.485	19.7	2.56E-02	50.034
18.2	2.35E-02	46.02	20	2.60E-02	50.836

Comparing result from Figure 19 and Table 4.6, deformation of the joint is 39.89 mm at final time (20th seconds) while from Table 4.6, the maximum deformation of 39.89 mm occurs at range of 15.7th seconds to 16.0th seconds. This shows that the flexibility of the joint is higher due to high axial force acting on the member.

4.4 Collapse Analysis (SACS)

Performing Collapse Analysis or Push – Over using SACS in this study is to validate the comparison of results between Static Structural Analysis (ANSYS) and In – Place Analysis (SACS). The structure of platform is pushed until it failed by increasing the load factor for dead load, live load and storm load (environmental load) with interval of 0.2. However, the result of stresses from In-Place Analysis is based on load factor of 1.0 for dead load, live load and storm load. Hence, the result from Collapse Analysis also will be focused on load factor of 1.0 for dead load, live load and storm load. Load step 15 is the condition whereby the load factor is 1.0 for all loads. Figure 4.11 shows the behavior of x - axis-Displacement for Joint 401 whereby in this case, the studied K- joint is labelled as Joint 401. At the load step of 15, the intersection point shows that the displacement would be range of 27 mm until 30 mm. The deflection to x-axis plane from In-Place Analysis is 28.77 mm. Hence, the result is validated as in range due to same load factor. Furthermore, the stress in each member are obtained as shown in Figure 4.12, 4.13, 4.14, 4.15 and 4.16 until reach failure. Hence, the stress of each member is determined based on load factor of 1.0.

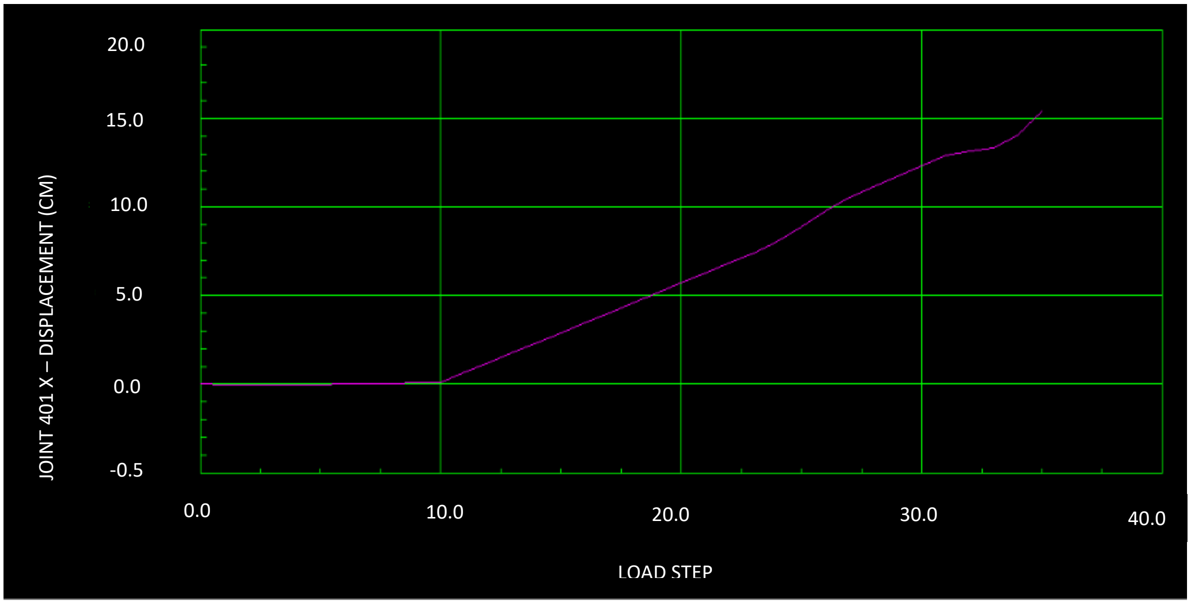


Figure 4.11: Graph of Joint 401 X - Displacement vs. Load Step

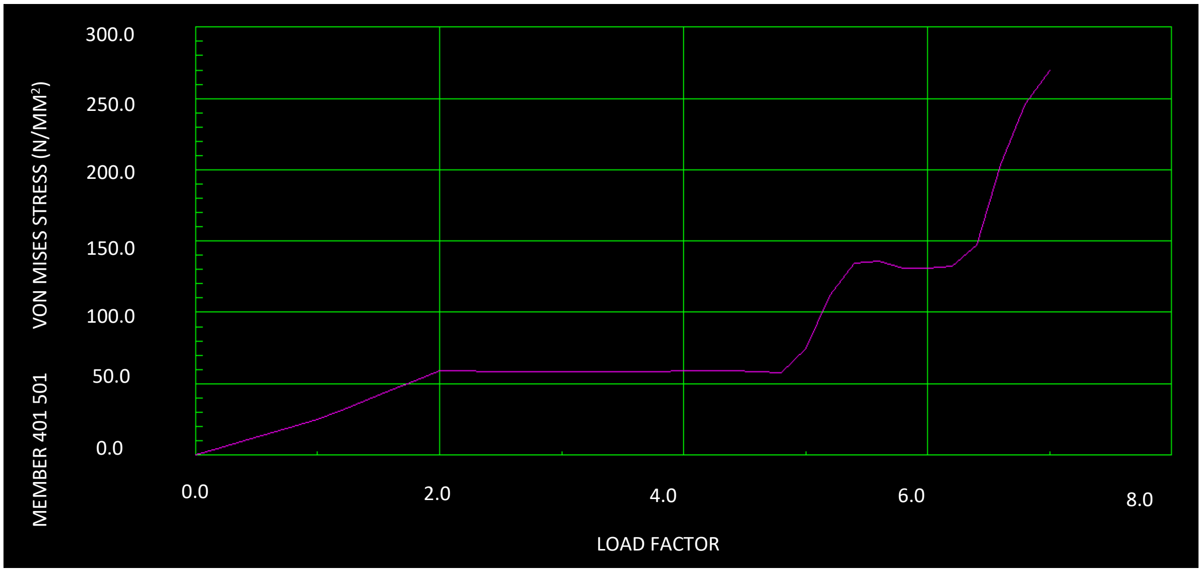


Figure 4.12: Graph of Stress (Von Mises) vs. Load Factor (Member L15)

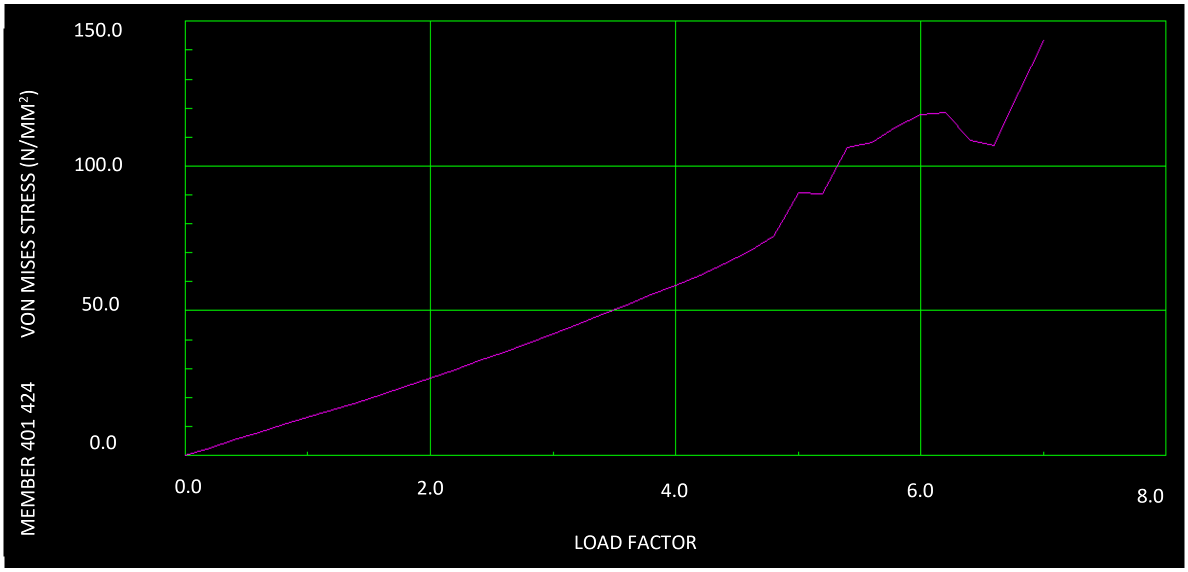


Figure 4.13: Graph of Stress (Von Mises) vs. Load Factor (Member 2KH)

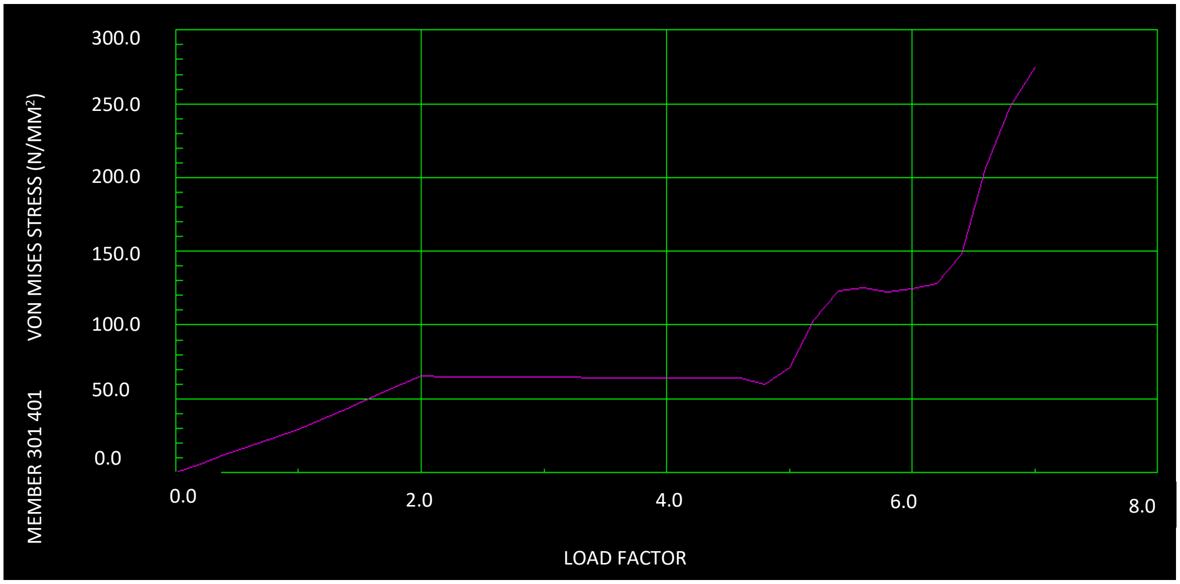


Figure 4.14: Graph of Stress (Von Mises) vs. Load Factor (Member L43)

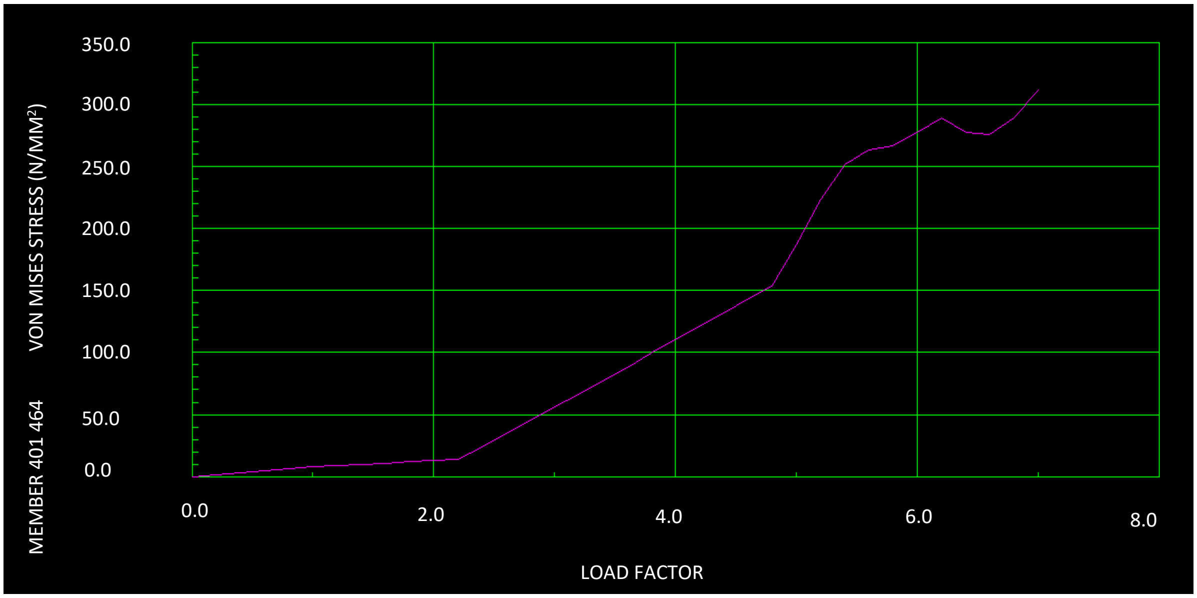


Figure 4.15: Graph of Stress (Von Mises) vs. Load Factor (Member V1F)

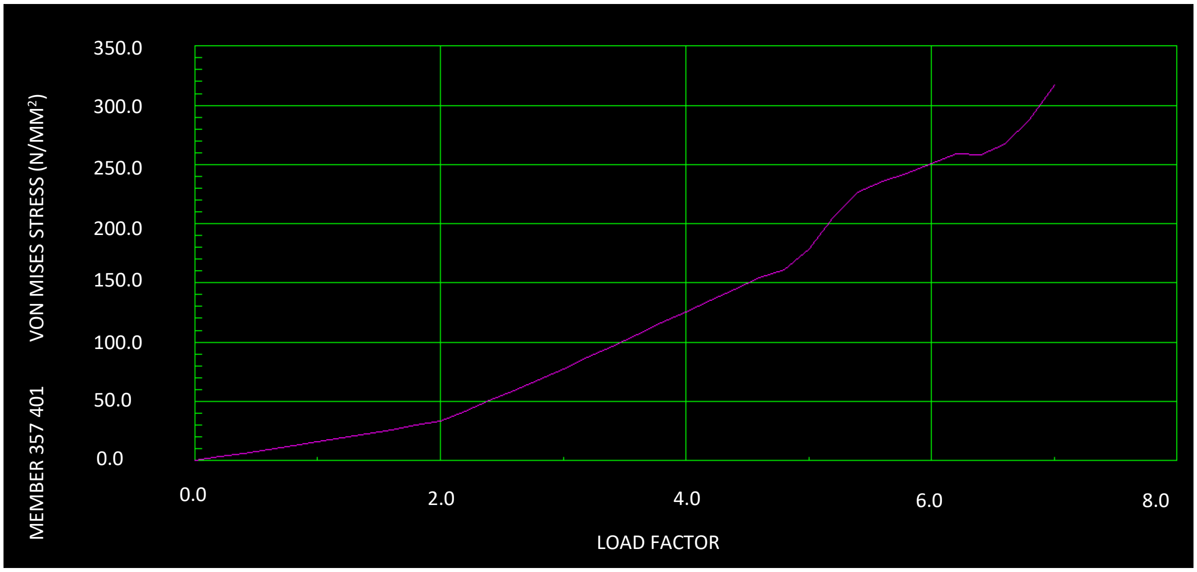


Figure 4.16: Graph of Stress (Von Mises) vs. Load Factor (Member V1T)

Based on Figure 4.12, 4.13, 4.14, 4.15 and 4.16, it shows that the value for stress (Von Mises) for each member are almost the same from results In-Place Analysis due to load factor of 1.0 for dead load, live load and storm load. Table 4.7 shows the results of stress in each member from Collapse Analysis and In Place Analysis. The results from Collapse Analysis are within range of ± 1.5 from the graph reading. Hence, results of stress of each member in Collapse Analysis (SACS) are lesser than results of stress of each member in Static Structural Analysis (ANSYS)

Table 4.7: Validation of stresses in each member

Member	**Load Case**	**Condition**	**Stress, σ (MPa) In-Place Analysis**	**Stress, σ (MPa) Collapse Analysis**
2KH	15	Tension	10.00	10.00
L15	15	Compression	20.55	20.00
L43	15	Compression	20.19	20.00
V1F	15	Tension	10.32	10.00
V1T	15	Compression	9.62	10.00

4.5 Discussion

The information of K – joint is extracted from In-Place Analysis Report (SACS) such as length of members, thickness, diameter, applied stresses, type of load, and deflection. From the information, geometry of K-joint has been remodel in AutoCAD according to the dimension. However, internal ring is not included in the geometry design because there will be no hydrostatic force applied on the members of K – joint. The purpose of internal ring is to overcome the hydrostatic force by stiffened the members. The geometry is imported in the ANSYS Workbench to performed static structural analysis. In the analysis, forces are applied in the tubular members in form of tension and compression. In the tubular members of K - joint, the axial loads in the brace should be balanced to within 10% by loads in other braces in the same plane and on the same side of the joint. The applied forces also including shear force acting on z-axis due to environmental loading such as wave and current.

The assigned material of the geometry is structural steel and the yield strength is 345 MPa. The density of material is 7850 kg/m^3. In this study, Bilinear Isotropic Hardening is used to obtain the behavior of the tubular members for deformation and stresses.

From the Static Structural Analysis (ANSYS), the results are to be obtained according to the objective of the study which is to determine the deformation and stresses reduction along the members. it is hypothesized that deformation at the joint (K - joint) in ANSYS is larger than deformation in SACS. The expected result is achieved since the deformation at the joint on x - axis is 39.89 mm in ANSYS while 28.77 mm in SACS. It is shows that the flexibility due to displacement could be up to 38.65 % from the original displacement in SACS. This is because analysis in SACS is performed in 1-D and considering overall Jacket structures. Furthermore, the analysis in ANSYS performed in 3-D and it is more flexible, focusing smaller elements and it is specific to the K- joint of the Jacket Platform (smaller element compared to overall Jacket structure in SACS). In other words, analysis in SACS is coarser compared to analysis in ANSYS.

It is believed that there would be stress reduction between the results of analysis in ANSYS and SACS. The expected result is stress in members in ANSYS less than stress in member in SACS. Table 4.8 presenting the data of stress in each member in while Figure 4.17 is illustrating the comparison of the stresses between Static Structural Analysis (ANSYS) and In- Place Analysis (SACS). The result of stresses has proven the conclusion in the study of “Role of Local Joint Flexibility (LJF) in the Structural Assessments of Ageing Offshore Structures”. The conclusion of the study made by Riaz Khan et al, (2016) which is the local joint flexibility at tubular joint allows a better redistribution of moment and stresses along the members of jacket truss structure. Hence, it is hypothesized that the lesser stress in the member is better.

Table 4.8: Results of stresses in each member between ANSYS and SACS's analysis

Member	**Stress, σ (MPa) in ANSYS**	**Stress, σ (MPa) in SACS**
2KH	1.0586	10.00
L15	10.516	20.55
L43	65.376	20.19
V1F	6.5373	10.32
V1T	5.7161	9.62

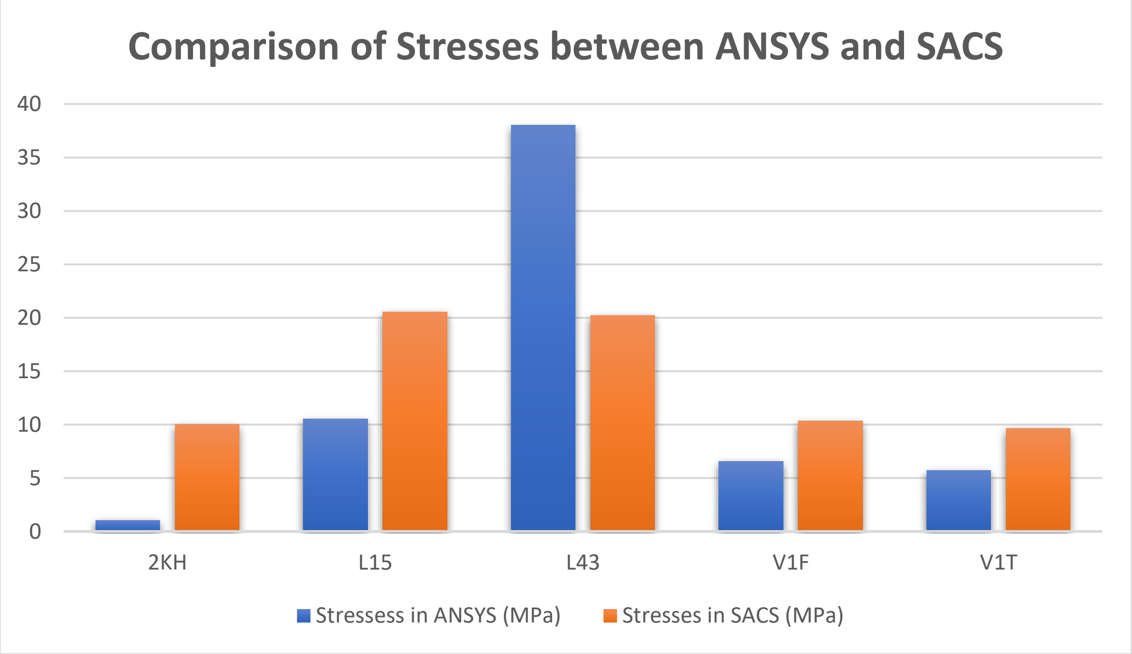


Figure 4.17: Comparison of stress of each member between Static Structural Analysis (ANSYS) and In-Place Analysis (SACS)

After performing both analysis in ANSYS and SACS, the result obtained are according to the objective. Stress in member 2KH, L15, V1F and V1T in ANSYS is lesser than stress in member in SACS. However, stress in ANSYS is larger than stress in SACS for member L43. In this case, assignment of fixed support in analysis setting in ANSYS could be the factor for obtaining higher stress. Furthermore, the actual case of the joint in

SACS is, more than two brace members are connected to the chord member (member L43) which is diagonal and horizontal braces as shown in Figure 4.18. Referring to Figure 4.7, there are no horizontal and diagonal braces member attached or connected at the end of member L43 in ANSYS.

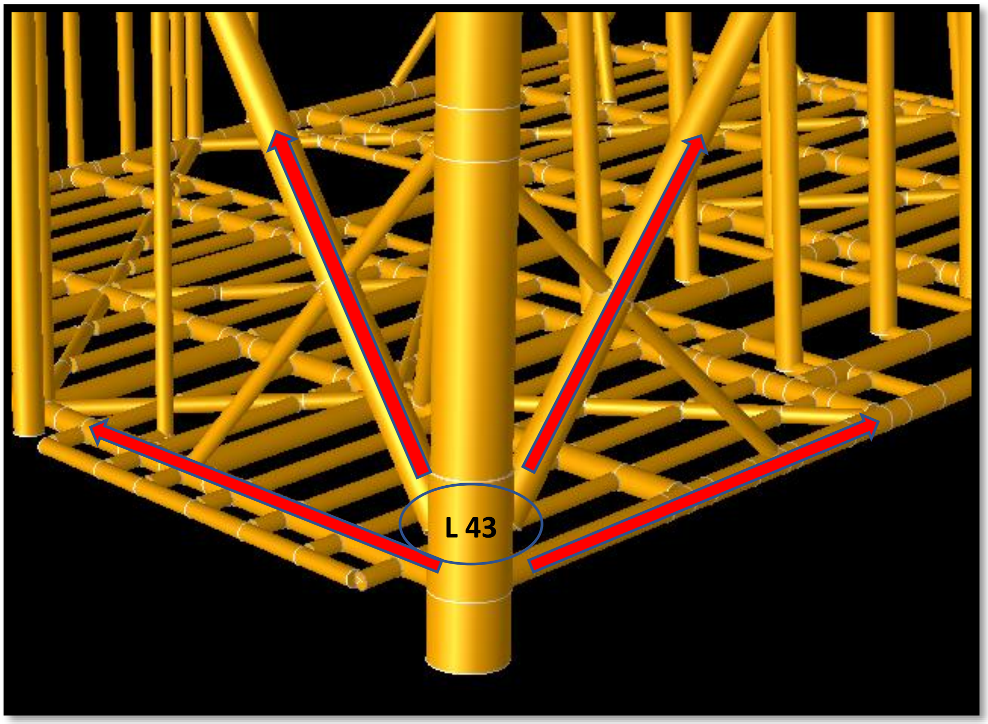


Figure 4.18: Four braces member connected to chord member (member L43) in SACS

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

It is found that deformation in ANSYS is as expected which is the deformation at the joint in ANSYS is bigger than deformation in SACS. The flexibility of K - joint in ANSYS due to displacement could be up to 38.65 % from the original displacement in SACS. Furthermore, it is also found that there is stress reduction between ANSYS and SACS at the joint due to load transfer in the members. From the comparison, higher stress with lesser deformation could be hypothesized. The results from ANSYS then is validated by performing Collapse Analysis (Push – Over) in SACS. In order to validate, results from In-Place Analysis are based on load factor of 1.0 for all loads. So, results of Collapse Analysis are to be focused to load factor of 1.0 for dead load, live load and storm load. For stress reduction, the value of stress in each member obtained from Static Structural Analysis (ANSYS) lesser than stresses from In-Place Analysis (SACS) and Collapse Analysis (ANSYS). As conclusion, LJF could be more flexible by obtaining higher deformation and able to reduce the stresses in the members of Jacket platform. Hence, it is believed that LJF would give positive impact to the condition assessment of Jacket Type Offshore Platform (JTOP) in order to determine the life extension period for future usage.

5.2 Recommendation

In this study, Bilinear Isotropic characteristic has been used as the engineering properties of the steel tubular members in Static Structural Analysis (ANSYS) as to determine the behavior of the steel tubular member. However, it is highly recommended that to apply the Multilinear Isotropic characteristic of stress-strain in the analysis. Figure 5.1 and 5.2 shows the Bilinear and Multilinear Isotropic characteristic. By applying Multilinear Isotropic, more accurate data could be obtain and able to produce a better understanding and research on the Local Joint Flexibility (LJF).

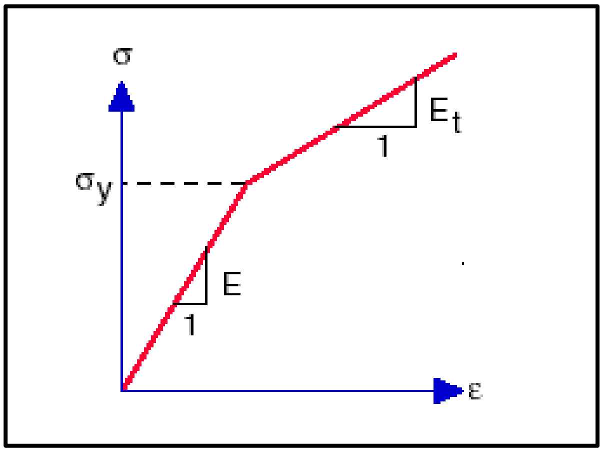


Figure 5.1: Bilinear Isotropic hardening

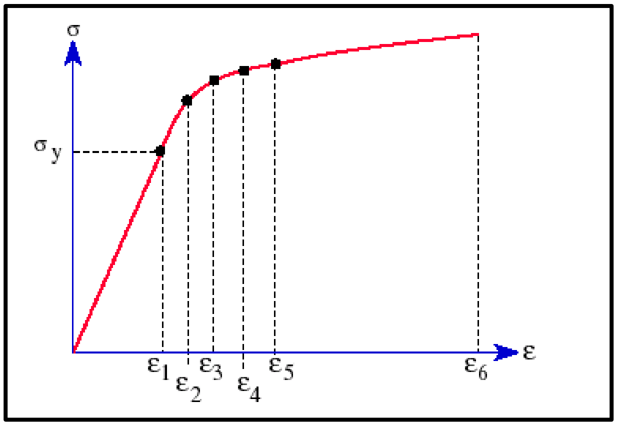


Figure 5.2: Multilinear Isotropic hardening

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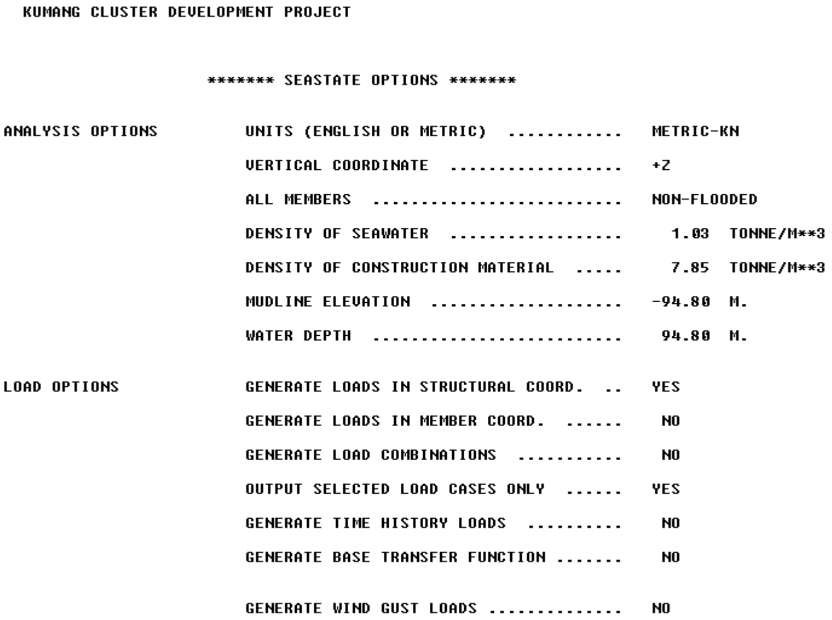
APPENDICES

IN – PLACE ANALYSIS REPORT



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  KUMANG CLUSTER DEVELOPMENT PROJECT


                   ******* SEASTATE OPTIONS *******

ANALYSIS OPTIONS         UNITS (ENGLISH OR METRIC)  ............   METRIC-KN

                         VERTICAL COORDINATE  ..................   +Z

                         ALL MEMBERS  ..........................   NON-FLOODED

                         DENSITY OF SEAWATER  ..................      1.03  TONNE/M**3

                         DENSITY OF CONSTRUCTION MATERIAL  .....      7.85  TONNE/M**3

                         MUDLINE ELEVATION  ....................   -94.80  M.

                         WATER DEPTH  ..........................    94.80  M.

LOAD OPTIONS             GENERATE LOADS IN STRUCTURAL COORD.  ..   YES

                         GENERATE LOADS IN MEMBER COORD.  ......    NO

                         GENERATE LOAD COMBINATIONS  ...........    NO

                         OUTPUT SELECTED LOAD CASES ONLY  ......   YES

                         GENERATE TIME HISTORY LOADS  ..........    NO

                         GENERATE BASE TRANSFER FUNCTION .......    NO


                         GENERATE WIND GUST LOADS ..............   NO
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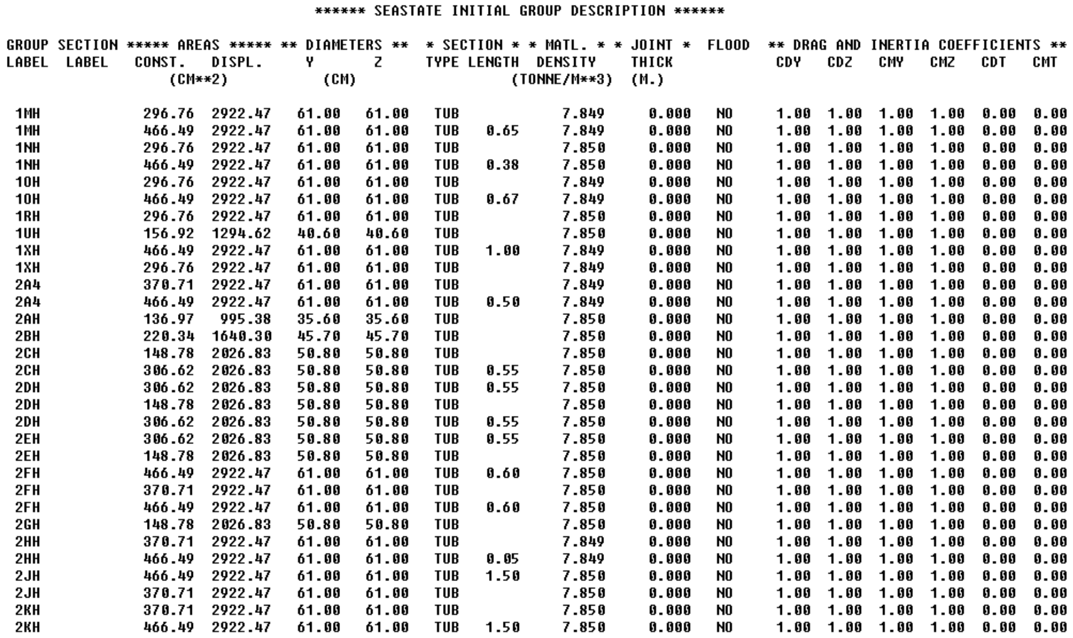

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                                ****** SEASTATE INITIAL GROUP DESCRIPTION ******

 GROUP SECTION ***** AREAS ***** ** DIAMETERS **  * SECTION * * MATL. * * JOINT *  FLOOD  ** DRAG AND INERTIA COEFFICIENTS **
 LABEL  LABEL    CONST.   DISPL.     Y       Z     TYPE LENGTH  DENSITY    THICK           CDY   CDZ   CMY   CMZ   CDT   CMT
                    (CM**2)            (CM)                    (TONNE/M**3)  (M.)

  1MH             296.76  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1MH             466.49  2922.47   61.00   61.00   TUB   0.65   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1NH             296.76  2922.47   61.00   61.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1NH             466.49  2922.47   61.00   61.00   TUB   0.38   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1OH             296.76  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1OH             466.49  2922.47   61.00   61.00   TUB   0.67   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1RH             296.76  2922.47   61.00   61.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1UH             156.92  1294.62   40.60   40.60   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1XH             466.49  2922.47   61.00   61.00   TUB   1.00   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  1XH             296.76  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2A4             370.71  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2A4             466.49  2922.47   61.00   61.00   TUB   0.50   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2AH             136.97   995.38   35.60   35.60   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2BH             220.34  1640.30   45.70   45.70   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2CH             148.78  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2CH             306.62  2026.83   50.80   50.80   TUB   0.55   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2DH             306.62  2026.83   50.80   50.80   TUB   0.55   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2DH             148.78  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2DH             306.62  2026.83   50.80   50.80   TUB   0.55   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2EH             306.62  2026.83   50.80   50.80   TUB   0.55   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2EH             148.78  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2FH             466.49  2922.47   61.00   61.00   TUB   0.60   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2FH             370.71  2922.47   61.00   61.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2FH             466.49  2922.47   61.00   61.00   TUB   0.60   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2GH             148.78  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2HH             370.71  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2HH             466.49  2922.47   61.00   61.00   TUB   0.05   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2JH             466.49  2922.47   61.00   61.00   TUB   1.50   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2JH             370.71  2922.47   61.00   61.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2KH             370.71  2922.47   61.00   61.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
  2KH             466.49  2922.47   61.00   61.00   TUB   1.50   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
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                          ****** SEASTATE INITIAL GROUP DESCRIPTION ******

GROUP SECTION ***** AREAS ***** ** DIAMETERS **  * SECTION * * MATL. * * JOINT *  FLOOD  ** DRAG AND INERTIA COEFFICIENTS **
LABEL  LABEL   CONST.   DISPL.     Y       Z     TYPE LENGTH  DENSITY    THICK            CDY   CDZ   CMY   CMZ   CDT   CMT
                 (CM**2)          (CM)                      (TONNE/M**3)  (M.)

 HE1           194.86  1294.62   40.60   40.60   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HE2           118.34  1294.62   40.60   40.60   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEE           299.24  1294.62   40.60   40.60   TUB   0.68   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEE           184.25  1294.62   40.60   40.60   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEF           299.24  1294.62   40.60   40.60   TUB   0.68   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEF           184.25  1294.62   40.60   40.60   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEF           299.24  1294.62   40.60   40.60   TUB   0.68   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 HEG           299.24  1294.62   40.60   40.60   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 JST           136.97   995.38   35.60   35.60   TUB          0.001     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 JT1           156.92  1294.62   40.60   40.60   TUB          0.001     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 JT2           197.62  2026.83   50.80   50.80   TUB          0.001     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 KB1           156.92  1294.62   40.60   40.60   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 KB2           197.62  2026.83   50.80   50.80   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 L11  G07    7039.71 22965.83  171.00  171.00   TUB          6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L12  G07    7039.71 22965.83  171.00  171.00   TUB   2.50   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L12  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L13  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L14  G07    7039.71 22965.83  171.00  171.00   TUB   2.00   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L14  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L14  G02    6771.89 22698.01  170.00  170.00   TUB   2.20   6.350     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L15  G07    7039.71 22965.83  171.00  171.00   TUB   2.10   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L15  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L15  G02    6771.89 22698.01  170.00  170.00   TUB   1.80   6.350     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L18  G03    6399.58 22325.70  168.60  168.60   TUB          6.263     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L31  G07    7039.71 22965.83  171.00  171.00   TUB          6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L32  G07    7039.71 22965.83  171.00  171.00   TUB   2.50   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L32  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L33  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L34  G07    7039.71 22965.83  171.00  171.00   TUB   2.00   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L34  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L34  G02    6771.89 22698.01  170.00  170.00   TUB   2.20   6.350     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L35  G07    7039.71 22965.83  171.00  171.00   TUB   2.30   6.407     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L35  G04    5197.96 21124.07  164.00  164.00   TUB          5.896     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
 L35  G02    6771.89 22698.01  170.00  170.00   TUB   1.80   6.350     0.000   YES    1.00  1.00  1.00  1.00  0.00  0.00
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                          ****** SEASTATE INITIAL GROUP DESCRIPTION ******

GROUP SECTION ***** AREAS ***** ** DIAMETERS **  * SECTION * * MATL. * * JOINT *  FLOOD  ** DRAG AND INERTIA COEFFICIENTS **
LABEL  LABEL   CONST.   DISPL.     Y       Z     TYPE LENGTH  DENSITY    THICK            CDY   CDZ   CMY   CMZ   CDT   CMT
                 (CM**2)          (CM)                      (TONNE/M**3)  (M.)

 V1F           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1F           506.39  3421.19   66.00   66.00   TUB   0.80   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1G           506.39  3421.19   66.00   66.00   TUB   0.80   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1G           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1H           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1I           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1N           245.81  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1Q           372.69  4560.37   76.20   76.20   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1R           372.69  4560.37   76.20   76.20   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1S           372.69  4560.37   76.20   76.20   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1S           587.78  4560.37   76.20   76.20   TUB   0.80   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1T           587.78  4560.37   76.20   76.20   TUB   0.80   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1T           372.69  4560.37   76.20   76.20   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1U           448.61  6561.18   91.40   91.40   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1U           881.34  6561.18   91.40   91.40   TUB   1.75   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1V           881.34  6561.18   91.40   91.40   TUB   1.75   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V1V           448.61  6561.18   91.40   91.40   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3A           398.16  5191.24   81.30   81.30   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3B           398.16  5191.24   81.30   81.30   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3C           466.21  4560.37   76.20   76.20   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3D           398.16  5191.24   81.30   81.30   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3E           448.61  6561.18   91.40   91.40   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3E           881.34  6561.18   91.40   91.40   TUB   1.70   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3F           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3F           506.39  3421.19   66.00   66.00   TUB   0.85   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3G           506.39  3421.19   66.00   66.00   TUB   0.85   7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3G           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3H           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3I           321.74  3421.19   66.00   66.00   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3J           448.61  6561.18   91.40   91.40   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3M           238.31  2922.47   61.00   61.00   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3M           577.64  2922.47   61.00   61.00   TUB   1.30   7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3N           245.81  2026.83   50.80   50.80   TUB          7.850     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
 V3Q           587.78  4560.37   76.20   76.20   TUB          7.849     0.000   NO     1.00  1.00  1.00  1.00  0.00  0.00
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                                          SACS-IV SYSTEM  MEMBER INTERNAL LOADS SUMMARY REPORT

               MAX. CRIT  LOAD  DIST  * * * * * * * * * *  I N T E R N A L   L O A D S  * * * * * * * * *   NEXT TWO HIGHEST CASES
 MEMBER  GRP  UNITY COND  COND  FROM    AXIAL       SHEAR       SHEAR     TORSION     BENDING     BENDING     UNITY  LD  UNITY  LD
              CHECK        NO.  END                 Y           Z                   Y-Y         Z-Z       CHECK  CN  CHECK  CN
                                  M     KN          KN          KN         KN-M        KN-M        KN-M

427- 425 2GH   0.28 HYDRO    DL  0.0   2.3608     0.11867     0.28910E-01-0.12035    -0.23390    -0.27775      0.3  LL09  0.2  ST09

434- 427 2GH   0.28 HYDRO    DL  0.0  -1.2541     0.48100E-01-0.12284E-01 0.35897E-01 0.49309E-01-0.21320      0.3  LL09  0.2  ST09

442- 445 2HH   0.06 TN+BN  LL09  0.0   358.78     0.97956     -1.5887    -0.39893      12.990      5.7606      0.0    DL  0.0  ST09

425- 404 2JH   0.07 TN+BN  LL09  5.3   449.78      6.9302    -0.70927      3.2672     -5.4262      17.718      0.1    DL  0.0  ST09

401- 424 2KH   0.07 TN+BN  LL09  0.0   466.27     -3.2119     -1.3185     -4.5489      8.5188      10.280      0.1  ST09  0.1    DL

426- 401 2LH   0.08 TN+BN  LL09  4.0   366.96      10.562     -6.6489     -1.7967     -37.854      25.338      0.1  ST09  0.1    DL

427- 404 2LH   0.05 TN+BN  ST09  4.0   189.39      2.0650     -7.9532     -13.061     -61.009      10.642      0.1  LL09  0.1    DL

429- 426 2MH   0.06 TN+BN  LL09  3.7   354.21     -4.9125     -5.4517     -3.6599     -10.023     -9.2881      0.1    DL  0.0  ST09

435- 427 2MH   0.05 HYDRO    DL  0.6   20.075     0.29676    -0.32466     0.91679E-01 0.37921    -0.75173      0.0  ST09  0.0  LL09

402- 447 2NH   0.05 HYDRO    DL  0.0   21.523    -0.47471    -0.68658E-01-0.20890     0.95663      1.5890      0.0  ST09  0.0  LL09

447- 490 2NH   0.04 HYDRO    DL  0.0   20.882     0.13711    -0.68658E-01-0.20890     0.53844    -0.62923      0.0  ST09  0.0  LL09

450- 403 2NH   0.09 C<.15  ST09  6.8  -269.57     -3.8985     -8.4217    -0.62879E-01 -49.698      16.622      0.1    DL  0.0  LL09

444- 441 2OH   0.05 HYDRO    DL  1.0   20.051    -0.40804     0.11855    -0.17344     0.51286      1.5248      0.0  LL09  0.0  ST09

402- 443 2PH   0.06 TN+BN  LL09  6.1   350.60     -3.2262      1.3187      1.6520      8.3219     -9.7617      0.1    DL  0.0  ST09

403- 444 2PH   0.06 TN+BN  ST09  0.0   301.63      8.8808     0.17462      5.6569      23.992     -50.634      0.1    DL  0.1  LL09

429- 430 2QH   0.20 HYDRO    DL  0.0   1.6679     0.95529    -0.50383E-01 0.18180     0.16268     -2.3907      0.2  LL09  0.1  ST09
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                                          SACS-IV SYSTEM  MEMBER INTERNAL LOADS SUMMARY REPORT

               MAX. CRIT  LOAD  DIST  * * * * * * * * * *  I N T E R N A L   L O A D S  * * * * * * * * *   NEXT TWO HIGHEST CASES
 MEMBER  GRP  UNITY COND  COND  FROM    AXIAL       SHEAR       SHEAR     TORSION     BENDING     BENDING     UNITY  LD  UNITY  LD
              CHECK        NO.  END                 Y           Z                   Y-Y         Z-Z       CHECK  CN  CHECK  CN
                                  M     KN          KN          KN         KN-M        KN-M        KN-M

302- 402 L42   0.11 TN+BN  ST09 23.8   8441.7      10.557     -55.972      39.181     -499.00      99.157      0.1  LL09  0.0    DL

303- 403 L42   0.06 C<.15  LL09  2.3  -3053.1      1.6861      4.1183      33.097     -142.25      10.789      0.0  ST09  0.0    DL

301- 401 L43   0.20 C>.15A LL09  2.3  -10448.     -14.488      12.440      37.251     -160.14      138.70      0.0    DL  0.0  ST09

304- 404 L43   0.18 C>.15A LL09  2.3  -9140.0      11.273      9.4938      5.9921     -161.85     -105.37      0.1  ST09  0.0    DL

180- 181 L44   0.16 TN+BN  ST09  0.0   12934.      96.074      165.88      31.508     -758.03      80.888      0.1  LL09  0.0    DL

183- 184 L44   0.05 C<.15  LL09  3.0  -2609.5      5.4627     -13.600     -2.5604     -129.48      173.28      0.0  ST09  0.0    DL

181- 202 L45   0.15 TN+BN  ST09  0.0   12922.     -79.180     -22.789      21.548     -228.10      393.37      0.1  LL09  0.0    DL

184- 203 L45   0.05 C<.15  LL09  0.0  -2609.0     -28.191      27.169     -3.7982     -147.11      162.85      0.0  ST09  0.0    DL

177- 178 L46   0.19 C>.15A LL09  3.0  -10535.     -9.5168      34.926     -2.7545      29.696     -228.69      0.0  ST09  0.0    DL

186- 187 L46   0.19 C>.15A ST09  0.0  -12869.     -34.578     -37.665     -2.7307      535.27      625.60      0.2  LL09  0.0    DL

178- 201 L47   0.20 C>.15A LL09  5.1  -10539.     -12.115      36.896     -2.0239      214.16     -289.52      0.0  ST09  0.0    DL

187- 204 L47   0.18 C>.15A ST09  0.0  -12851.     -45.292     -43.817     -1.1658      429.85      528.86      0.2  LL09  0.0    DL

918- 925 L48   0.17 C>.15A LL09  3.4  -9330.6      170.95      66.694      109.60      154.00      348.34      0.0  ST09  0.0    DL

919- 926 L48   0.14 C<.15  LL09  3.4  -7358.3     -150.91      19.378      30.673     -111.19     -309.49      0.0  ST09  0.0    DL

729- 715 L49   0.07 C<.15  LL09  4.8  -3286.0     -58.078     -25.791      114.35     -388.70     -596.78      0.0  ST09  0.0    DL

738- 739 L49   0.14 C<.15  LL09  4.8  -7710.6     -34.229     -43.603      34.722     -526.11     -395.93      0.1  ST09  0.0    DL

601- 924 L50   0.16 C<.15  LL09  1.6  -9494.5     -245.48      41.009      71.464     -164.54      512.28      0.0  ST09  0.0    DL
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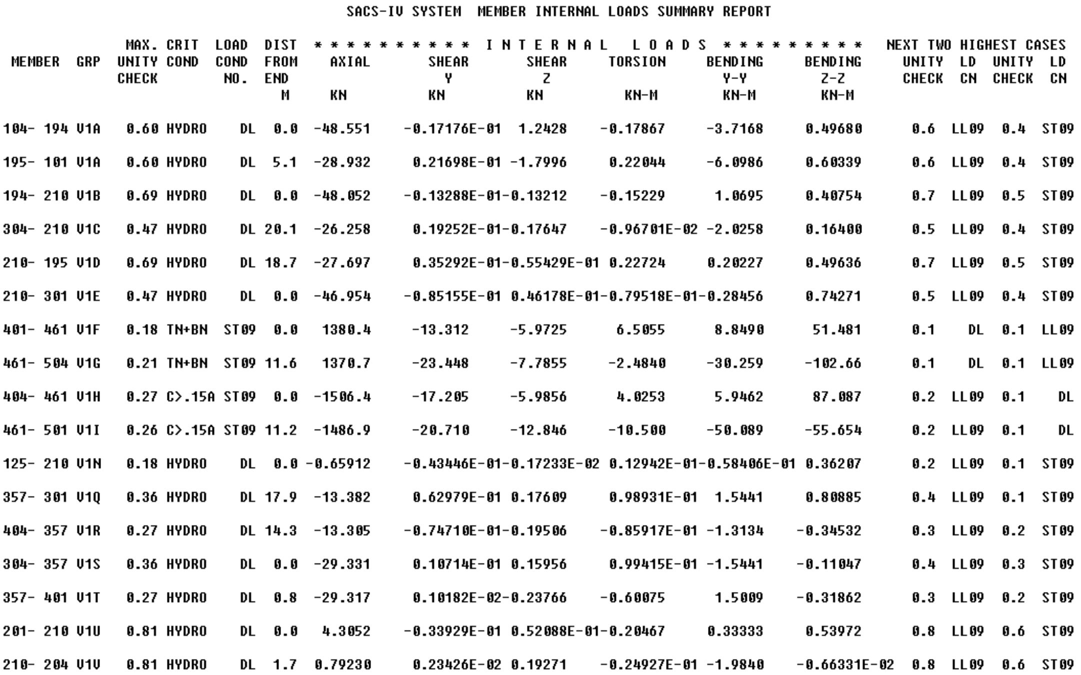

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                                         SACS-IV SYSTEM  MEMBER INTERNAL LOADS SUMMARY REPORT

              MAX. CRIT  LOAD  DIST  * * * * * * * * * *  I N T E R N A L   L O A D S  * * * * * * * * *   NEXT TWO HIGHEST CASES
 MEMBER  GRP UNITY COND  COND  FROM    AXIAL      SHEAR       SHEAR     TORSION     BENDING     BENDING    UNITY  LD  UNITY  LD
             CHECK        NO.  END                  Y           Z                     Y-Y         Z-Z       CHECK  CN  CHECK  CN
                                 M     KN          KN          KN          KN-M        KN-M        KN-M

104- 194 V1A  0.60 HYDRO    DL   0.0  -48.551   -0.17176E-01  1.2428   -0.17867     -3.7168     0.49680     0.6  LL09  0.4  ST09

195- 101 V1A  0.60 HYDRO    DL   5.1  -28.932    0.21698E-01 -1.7996    0.22044     -6.0986     0.60339     0.6  LL09  0.4  ST09

194- 210 V1B  0.69 HYDRO    DL   0.0  -48.052   -0.13288E-01-0.13212   -0.15229      1.0695     0.40754     0.7  LL09  0.5  ST09

304- 210 V1C  0.47 HYDRO    DL  20.1  -26.258    0.19252E-01-0.17647   -0.96701E-02 -2.0258     0.16400     0.5  LL09  0.4  ST09

210- 195 V1D  0.69 HYDRO    DL  18.7  -27.697    0.35292E-01-0.55429E-01 0.22724     0.20227     0.49636     0.7  LL09  0.5  ST09

210- 301 V1E  0.47 HYDRO    DL   0.0  -46.954   -0.85155E-01 0.46178E-01-0.79518E-01-0.28456     0.74271     0.5  LL09  0.4  ST09

401- 461 V1F  0.18 TN+BN  ST09   0.0   1380.4     -13.312     -5.9725     6.5055      8.8490      51.481     0.1    DL  0.1  LL09

461- 504 V1G  0.21 TN+BN  ST09  11.6   1370.7     -23.448     -7.7855    -2.4840     -30.259     -102.66     0.1    DL  0.1  LL09

404- 461 V1H  0.27 C>.15A ST09   0.0  -1506.4     -17.205     -5.9856     4.0253      5.9462      87.087     0.2  LL09  0.1    DL

461- 501 V1I  0.26 C>.15A ST09  11.2  -1486.9     -20.710     -12.846    -10.500     -50.089     -55.654     0.2  LL09  0.1    DL

125- 210 V1N  0.18 HYDRO    DL   0.0 -0.65912   -0.43446E-01-0.17233E-02 0.12942E-01-0.58406E-01 0.36207     0.2  LL09  0.1  ST09

357- 301 V1Q  0.36 HYDRO    DL  17.9  -13.382    0.62979E-01 0.17609    0.98931E-01  1.5441     0.80885     0.4  LL09  0.1  ST09

404- 357 V1R  0.27 HYDRO    DL  14.3  -13.305   -0.74710E-01-0.19506   -0.85917E-01 -1.3134    -0.34532     0.3  LL09  0.2  ST09

304- 357 V1S  0.36 HYDRO    DL   0.0  -29.331    0.10714E-01 0.15956    0.99415E-01 -1.5441    -0.11047     0.4  LL09  0.3  ST09

357- 401 V1T  0.27 HYDRO    DL   0.8  -29.317    0.10182E-02-0.23766   -0.60075      1.5009    -0.31862     0.3  LL09  0.2  ST09

201- 210 V1U  0.81 HYDRO    DL   0.0   4.3052   -0.33929E-01 0.52088E-01-0.20467     0.33333     0.53972     0.8  LL09  0.6  ST09

210- 204 V1V  0.81 HYDRO    DL   1.7  0.79230    0.23426E-02 0.19271   -0.24927E-01 -1.9840    -0.66331E-02 0.8  LL09  0.6  ST09
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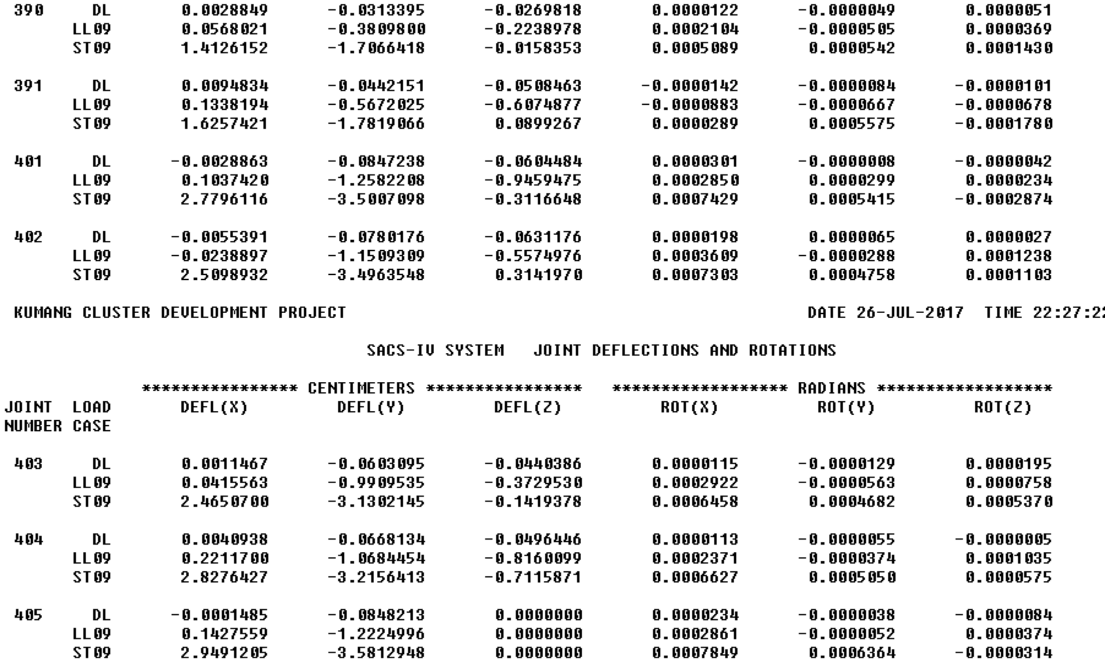

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 390      DL         0.0028849        -0.0313395        -0.0269818          0.0000122        -0.0000049          0.0000051
        LL09         0.0568021        -0.3809800        -0.2238978          0.0002104        -0.0000505          0.0000369
        ST09         1.4126152        -1.7066418        -0.0158353          0.0005089         0.0000542          0.0001430

 391      DL         0.0094834        -0.0442151        -0.0508463         -0.0000142        -0.0000084         -0.0000101
        LL09         0.1338194        -0.5672025        -0.6074877         -0.0000883        -0.0000667         -0.0000678
        ST09         1.6257421        -1.7819066         0.0899267          0.0000289         0.0005575         -0.0001780

 401      DL        -0.0028863        -0.0847238        -0.0604484          0.0000301        -0.0000008         -0.0000042
        LL09         0.1037420        -1.2582208        -0.9459475          0.0002850         0.0000299          0.0000234
        ST09         2.7796116        -3.5007098        -0.3116648          0.0007429         0.0005415         -0.0002874

 402      DL        -0.0055391        -0.0780176        -0.0631176          0.0000198         0.0000065          0.0000027
        LL09        -0.0238897        -1.1509309        -0.5574976          0.0003609        -0.0000288          0.0001238
        ST09         2.5098932        -3.4963548         0.3141970          0.0007303         0.0004758          0.0001103

 KUMANG CLUSTER DEVELOPMENT PROJECT                                                           DATE 26-JUL-2017  TIME 22:27:2

                                          SACS-IV SYSTEM   JOINT DEFLECTIONS AND ROTATIONS

                ***************** CENTIMETERS ****************   ****************** RADIANS ******************
JOINT   LOAD         DEFL(X)           DEFL(Y)           DEFL(Z)             ROT(X)            ROT(Y)             ROT(Z)
NUMBER CASE

 403      DL         0.0011467        -0.0603095        -0.0440386          0.0000115        -0.0000129          0.0000195
        LL09         0.0415563        -0.9909535        -0.3729530          0.0002922        -0.0000563          0.0000758
        ST09         2.4650700        -3.1302145        -0.1419378          0.0006458         0.0004682          0.0005370

 404      DL         0.0040938        -0.0668134        -0.0496446          0.0000113        -0.0000055         -0.0000005
        LL09         0.2211700        -1.0684454        -0.8160099          0.0002371        -0.0000374          0.0001035
        ST09         2.8276427        -3.2156413        -0.7115871          0.0006627         0.0005050          0.0000575

 405      DL        -0.0001485        -0.0848213         0.0000000          0.0000234        -0.0000038         -0.0000084
        LL09         0.1427559        -1.2224996         0.0000000          0.0002861        -0.0000052          0.0000374
        ST09         2.9491205        -3.5812948         0.0000000          0.0007849         0.0006364         -0.0000314
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                                      SACS-IV SYSTEM   ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

              MAXIMUM CRITICAL LOAD DIST  ********** APPLIED STRESSES **********  * CM VALUES *   * NEXT TWO HIGHEST CASES *
 MEMBER  GRP    UNITY   COND.  CASE FROM  AXIAL  ** BENDING **   *** SHEAR ***                       UNITY LOAD    UNITY LOAD
                CHECK           NO. END             Y-Y     Z-Z      Y       Z        Y       Z      CHECK COND    CHECK COND
                                      M    N/MM2   N/MM2   N/MM2   N/MM2   N/MM2

434- 427 2GH    0.275   HYDRO    DL  0.00  -0.08    0.03   -0.12    0.01    0.01     0.85    0.85     0.28 LL09     0.21 ST09

442- 445 2HH    0.057   TN+BN  LL09  0.00   9.68    2.45    1.09    0.10   -0.04     0.85    0.85     0.04   DL     0.03 ST09
                0.045   TN+BN  LL09  1.94   7.69    1.51    1.17    0.08   -0.03     0.85    0.85     0.03   DL     0.02 ST09

425- 404 2JH    0.058   TN+BN  LL09  0.00   9.64   -0.25   -2.90    0.30    0.25     0.85    0.85     0.04   DL     0.03 ST09
                0.072   TN+BN  LL09  5.30  12.13   -1.02    3.35    0.38    0.31     0.85    0.85     0.05   DL     0.04 ST09

401- 424 2KH    0.071   TN+BN  LL09  0.00  12.58    1.61    1.94    0.19   -0.43     0.85    0.85     0.06 ST09     0.05   DL
                0.052   TN+BN  LL09  5.30  10.00    0.23   -1.03    0.15   -0.35     0.85    0.85     0.04   DL     0.03 ST09

426- 401 2LH    0.050   TN+BN  LL09  0.00   7.87   -1.72   -2.57    0.54   -0.14     0.85    0.85     0.04   DL     0.03 ST09
                0.081   TN+BN  LL09  3.99   9.90   -7.15    4.79    0.67   -0.17     0.85    0.85     0.07 ST09     0.05   DL

427- 404 2LH    0.036   HYDRO    DL  0.00   0.38   -0.12    0.20    0.03    0.00     0.85    0.85     0.04 LL09     0.03 ST09
                0.052   TN+BN  ST09  3.99   5.11  -11.52    2.01    0.44   -1.23     0.85    0.85     0.05 LL09     0.05   DL

429- 426 2MH    0.045   TN+BN  LL09  0.00   7.59    1.59    1.40    0.31   -0.28     0.85    0.85     0.04   DL     0.03 ST09
                0.056   TN+BN  LL09  3.75   9.56   -1.89   -1.75    0.40   -0.35     0.85    0.85     0.05   DL     0.04 ST09
                0.050   TN+BN  LL09  4.85   7.59   -2.45   -2.24    0.31   -0.28     0.85    0.85     0.04   DL     0.03 ST09

435- 427 2MH    0.036   HYDRO    DL  0.00   0.43    0.09   -0.14    0.02    0.01     0.85    0.85     0.03 LL09     0.03 ST09
                0.051   HYDRO    DL  0.65   0.54    0.07   -0.14    0.02    0.01     0.85    0.85     0.04 ST09     0.04 LL09
                0.036   HYDRO    DL  3.75   0.43   -0.10    0.03    0.02    0.01     0.85    0.85     0.04 ST09     0.03 LL09

402- 447 2NH    0.051   HYDRO    DL  0.00   0.58    0.18    0.30    0.03   -0.02     0.85    0.85     0.04 ST09     0.04 LL09

447- 490 2NH    0.043   HYDRO    DL  0.00   0.56    0.10   -0.12    0.01   -0.02     0.85    0.85     0.04 ST09     0.03 LL09

450- 403 2NH    0.086   C<.15  ST09  6.81  -7.27   -9.39    3.14    0.50   -0.01     0.85    0.85     0.05   DL     0.04 LL09
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                                      SACS-IV SYSTEM   ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

              MAXIMUM CRITICAL LOAD DIST  ********** APPLIED STRESSES **********  * CM VALUES *   * NEXT TWO HIGHEST CASES *
 MEMBER  GRP    UNITY   COND.  CASE FROM  AXIAL  ** BENDING **   *** SHEAR ***                       UNITY LOAD    UNITY LOAD
                CHECK           NO. END             Y-Y     Z-Z      Y       Z        Y       Z      CHECK COND    CHECK COND
                                      M    N/MM2   N/MM2   N/MM2   N/MM2   N/MM2

166- 184 KB2    0.345   HYDRO    DL  0.00  -0.02   -0.13   -0.02    0.00    0.01     0.85    0.85     0.35 LL09     0.26 ST09

178- 148 KB2    0.345   HYDRO    DL 14.65   0.01   -0.14    0.00    0.00   -0.01     0.85    0.85     0.35 LL09     0.26 ST09

187- 149 KB2    0.345   HYDRO    DL 14.65   0.02   -0.13   -0.01    0.00    0.00     0.85    0.85     0.35 LL09     0.26 ST09

100A- 101 L11   0.000   C<.15    DL  0.00   0.00    0.00    0.00    0.00    0.00     0.85    0.85     0.00 LL09     0.00 ST09

100D- 104 L11   0.000   C<.15    DL  0.00   0.00    0.00    0.00    0.00    0.00     0.85    0.85     0.00 LL09     0.00 ST09

101- 176 L12    0.126   C<.15  LL09  0.00 -20.28   -1.60   -0.81    0.05   -0.01     0.85    0.85     0.03 ST09     0.01   DL
                0.192   C>.15A LL09  2.50 -31.49   -1.99   -1.43    0.08   -0.03     0.85    0.85     0.05 ST09     0.01   DL

104- 185 L12    0.130   C<.15  ST09  0.00 -24.89    5.23    4.75    0.12    0.00     0.85    0.85     0.11 LL09     0.01   DL
                0.198   C>.15A ST09  2.50 -38.65    7.31    6.95    0.17   -0.01     0.85    0.85     0.17 LL09     0.01   DL

176- 177 L13    0.191   C>.15A LL09  0.00 -31.58   -0.94   -1.77    0.11   -0.03     0.85    0.85     0.04 ST09     0.01   DL

185- 186 L13    0.190   C>.15A ST09  0.00 -38.65    4.86    5.43    0.14   -0.05     0.85    0.85     0.17 LL09     0.01   DL

201- 301 L14    0.125   C<.15  LL09  0.00 -20.39    1.52   -1.73    0.08   -0.02     0.85    0.85     0.01   DL     0.01 ST09
                0.192   C>.15A LL09  2.00 -31.66    1.95   -2.26    0.12   -0.05     0.85    0.85     0.01 ST09     0.01   DL
                0.128   C<.15  LL09 17.59 -21.50   -1.15    1.10    0.08   -0.02     0.85    0.85     0.01 ST09     0.01   DL

204- 304 L14    0.112   C<.15  LL09  0.00 -18.57    0.55    1.58    0.06    0.16     0.85    0.85     0.11 ST09     0.01   DL
                0.172   C>.15A LL09  2.00 -28.83    0.60    2.10    0.09    0.45     0.85    0.85     0.17 ST09     0.01   DL
                0.116   C<.15  LL09 17.59 -19.58   -1.08   -0.84    0.06    0.18     0.85    0.85     0.11 ST09     0.01   DL

401- 501 L15    0.120   C<.15  LL09  0.00 -19.48    0.60   -1.04    0.03    0.27     0.85    0.85     0.01   DL     0.01 ST09
                0.183   C>.15A LL09  2.10 -30.25    0.79   -1.46    0.05    0.76     0.85    0.85     0.02   DL     0.01 ST09
                0.123   C<.15  LL09 20.60 -20.55   -0.48    0.24    0.03    0.30     0.85    0.85     0.01   DL     0.01 ST09
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                      SACS-IV SYSTEM   ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

             MAXIMUM CRITICAL LOAD  DIST  ********** APPLIED STRESSES **********  * CM VALUES *  * NEXT TWO HIGHEST CASES *
 MEMBER  GRP  UNITY    COND.  CASE  FROM   AXIAL   ** BENDING **   *** SHEAR ***                     UNITY LOAD    UNITY LOAD
              CHECK            NO.  END              Y-Y     Z-Z       Y       Z       Y       Z     CHECK COND    CHECK COND
                                     M     N/MM2   N/MM2   N/MM2   N/MM2   N/MM2

303- 403 L42   0.043   C<.15  LL09  0.00   -6.22   -0.85    0.04    0.01    0.16    0.85    0.85     0.01   DL     0.00 ST09
               0.062   C<.15  LL09  2.30   -9.16   -1.21    0.09    0.01    0.41    0.85    0.85     0.01 ST09     0.01   DL
               0.040   C<.15  LL09 23.83   -5.90   -0.28    0.25    0.01    0.14    0.85    0.85     0.01 ST09     0.01   DL

301- 401 L43   0.142   C<.15  LL09  0.00  -21.29   -1.06    0.97    0.04    0.18    0.85    0.85     0.01   DL     0.00 ST09
               0.201   C>.15A LL09  2.30  -31.34   -1.36    1.18    0.06    0.46    0.85    0.85     0.01   DL     0.01 ST09
               0.136   C<.15  LL09 26.13  -20.19    0.72   -1.10    0.04    0.16    0.85    0.85     0.01   DL     0.01 ST09

304- 404 L43   0.124   C<.15  LL09  0.00  -18.63   -1.03   -0.74    0.03    0.03    0.85    0.85     0.09 ST09     0.01   DL
               0.176   C>.15A LL09  2.30  -27.42   -1.38   -0.90    0.04    0.07    0.85    0.85     0.13 ST09     0.01   DL
               0.118   C<.15  LL09 26.13  -17.66    0.34    0.87    0.03    0.03    0.85    0.85     0.09 ST09     0.01   DL

180- 181 L44   0.163   TN+BN  ST09  0.00   38.80   -6.45    0.69    0.58    0.39    0.85    0.85     0.08 LL09     0.01   DL

183- 184 L44   0.054   C<.15  LL09  3.02   -7.83   -1.10    1.47    0.04   -0.03    0.85    0.85     0.03 ST09     0.01   DL

181- 202 L45   0.154   TN+BN  ST09  0.00   38.77   -1.94    3.35    0.25    0.26    0.85    0.85     0.08 LL09     0.01   DL
               0.099   TN+BN  ST09  7.18   24.97   -2.11   -0.93    0.16    0.09    0.85    0.85     0.05 LL09     0.01   DL

184- 203 L45   0.054   C<.15  LL09  0.00   -7.83   -1.25    1.39    0.12   -0.05    0.85    0.85     0.02 ST09     0.01   DL
               0.031   C<.15  LL09  7.18   -5.04    0.25   -0.21    0.08   -0.02    0.85    0.85     0.00   DL     0.00 ST09

177- 178 L46   0.191   C>.15A LL09  3.01  -31.61    0.25   -1.95    0.11   -0.03    0.85    0.85     0.03 ST09     0.01   DL

186- 187 L46   0.189   C>.15A ST09  0.00  -38.61    4.56    5.32    0.15   -0.03    0.85    0.85     0.17 LL09     0.01   DL

178- 201 L47   0.195   C>.15A LL09  5.05  -31.62    1.82   -2.46    0.12   -0.02    0.85    0.85     0.02 ST09     0.01   DL
               0.128   C<.15  LL09  7.05  -20.37    1.53   -1.67    0.08   -0.01    0.85    0.85     0.01   DL     0.01 ST09

187- 204 L47   0.185   C>.15A ST09  0.00  -38.55    3.66    4.50    0.19   -0.01    0.85    0.85     0.18 LL09     0.01   DL
               0.115   C<.15  LL09  7.05  -18.54    0.58    1.61    0.03    0.12    0.85    0.85     0.12 ST09     0.01   DL
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                      SACS-IV SYSTEM   ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

             MAXIMUM CRITICAL LOAD  DIST  ********** APPLIED STRESSES **********  * CM VALUES *  * NEXT TWO HIGHEST CASES *
 MEMBER  GRP  UNITY    COND.  CASE  FROM   AXIAL   ** BENDING **   *** SHEAR ***                     UNITY LOAD    UNITY LOAD
              CHECK            NO.  END              Y-Y     Z-Z       Y       Z       Y       Z     CHECK COND    CHECK COND
                                     M     N/MM2   N/MM2   N/MM2   N/MM2   N/MM2
               0.115   TN+BN  ST09 13.86   27.29    0.48   -5.59    0.22    0.42    0.85    0.85     0.03   DL     0.03 LL09

461- 504 V1G   0.120   TN+BN  ST09  0.00   27.04   -2.00    7.48    0.29   -0.16    0.85    0.85     0.03   DL     0.03 LL09
               0.213   TN+BN  ST09 11.56   42.60   -5.98  -20.29    1.54   -0.25    0.85    0.85     0.08   DL     0.08 LL09

404- 461 V1H   0.273   C>.15A ST09  0.00  -46.82    1.18   17.21    1.13    0.40    0.85    0.85     0.17 LL09     0.12   DL

461- 501 V1I   0.263   C>.15A ST09 11.23  -46.21   -9.90  -11.00    1.51   -1.04    0.85    0.85     0.19 LL09     0.08   DL

125- 210 V1N   0.176   HYDRO    DL  0.00   -0.03   -0.02    0.12    0.00    0.00    0.85    0.85     0.18 LL09     0.13 ST09

357- 301 V1Q   0.355   HYDRO    DL 17.88   -0.36    0.23    0.12    0.01    0.01    0.85    0.85     0.36 LL09     0.14 ST09

404- 357 V1R   0.269   HYDRO    DL 14.33   -0.36   -0.19   -0.05    0.01   -0.01    0.85    0.85     0.27 LL09     0.16 ST09

304- 357 V1S   0.355   HYDRO    DL  0.00   -0.79   -0.23   -0.02    0.01    0.01    0.85    0.85     0.36 LL09     0.27 ST09
               0.177   C>.15A LL09 18.26   -9.62    2.10    0.05    0.09    0.00    0.85    0.85     0.17 ST09     0.07   DL

357- 401 V1T   0.179   C>.15A LL09  0.00   -9.62    2.64   -0.03    0.14   -0.13    0.85    0.85     0.16 ST09     0.07   DL
               0.267   HYDRO    DL  0.80   -0.79    0.22   -0.05    0.01   -0.04    0.85    0.85     0.27 LL09     0.23 ST09

201- 210 V1U   0.814   HYDRO    DL  0.00    0.10    0.03    0.05    0.00   -0.01    0.85    0.85     0.81 LL09     0.61 ST09
               0.112   HYDRO    DL 12.55    0.05    0.05    0.01    0.00   -0.01    0.85    0.85     0.11 LL09     0.08 ST09

210- 204 V1V   0.112   HYDRO    DL  0.00    0.01   -0.12    0.00    0.00    0.00    0.85    0.85     0.11 LL09     0.08 ST09
               0.814   HYDRO    DL  1.75    0.02   -0.20    0.00    0.01    0.00    0.85    0.85     0.81 LL09     0.61 ST09

103- 191 V3A   0.598   HYDRO    DL  0.00   -0.91   -0.32   -0.10    0.05   -0.01    0.85    0.85     0.60 LL09     0.45 ST09

190- 102 V3A   0.598   HYDRO    DL  5.14   -0.50   -0.62   -0.09    0.07    0.00    0.85    0.85     0.60 LL09     0.26 ST09

207- 190 V3B   0.686   HYDRO    DL 18.80   -0.48    0.00    0.10    0.00    0.01    0.85    0.85     0.69 LL09     0.33 ST09

302- 207 V3C   0.235   HYDRO    DL 20.24   -0.89    0.01    0.00    0.00    0.00    0.85    0.85     0.24 LL09     0.18 ST09
```

STATIC STRUCTURAL ANALYSIS REPORT

Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (E4)

Geometry

TABLE 2
Model (E4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	D:\FYP\ANSYS\FYP K Joint Working\FYP K-joint Working_files\dp0\SYS-5\DM\SYS-5.scdoc
Type	SpaceClaim

Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	9188.4 mm
Length Y	46732 mm
Length Z	1710. mm
Properties	
Volume	6.0645e+010 mm³
Mass	4.7607e+005 kg
Surface Area(approx.)	6.0645e+008 mm²
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	14851
Elements	14879
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	Yes
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes

Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\User\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (E4) > Geometry > Parts

Object Name	*FYP K-Joint 2\ SURF*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Thickness	100. mm

Thickness Mode	Manual
Offset Type	Middle
Behavior	None
Material	
Assignment	Structural Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	9188.4 mm
Length Y	46732 mm
Length Z	1710. mm
Properties	
Volume	6.0645e+010 mm³
Mass	4.7607e+005 kg
Centroid X	-2566.5 mm
Centroid Y	-5413.1 mm
Centroid Z	6.3673e-003 mm
Moment of Inertia Ip1	7.3993e+013 kg·mm²
Moment of Inertia Ip2	2.0826e+012 kg·mm²
Moment of Inertia Ip3	7.5815e+013 kg·mm²
Surface Area(approx.)	6.0645e+008 mm²
Statistics	
Nodes	14851
Elements	14879
Mesh Metric	None
CAD Attributes	
PartTolerance:	0.00000001
Color:30.30.30	

Coordinate Systems

TABLE 4
Model (E4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. mm
Origin Y	0. mm
Origin Z	0. mm
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Connections

TABLE 5
Model (E4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

Mesh

TABLE 6
Model (E4) > Mesh

Object Name	*Mesh*
State	Solved

Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Element Midside Nodes	Program Controlled
Sizing	
Size Function	Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Span Angle Center	Coarse
Curvature Normal Angle	Default (30.0 °)
Min Size	Default (134.270 mm)
Max Face Size	Default (671.340 mm)
Growth Rate	Default
Automatic Mesh Based Defeaturing	On
Defeature Size	Default (67.1340 mm)
Minimum Edge Length	3.2202e-002 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	2

Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	No
Number of Retries	0
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (120.840 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Statistics	
Nodes	14851
Elements	14879

TABLE 7
Model (E4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Type	Element Size
Element Size	200. mm
Advanced	

Defeature Size	Default (67.134 mm)
Size Function	Uniform
Behavior	Soft
Growth Rate	Default (1.850)

Static Structural (E5)

TABLE 8
Model (E4) > Analysis

Object Name	*Static Structural (E5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22. °C
Generate Input Only	No

TABLE 9
Model (E4) > Static Structural (E5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	20.
Current Step Number	20.
Step End Time	20. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Off

Solver Pivot Checking	Program Controlled
Rotordynamics Controls	
Coriolis Effect	Off
Restart Controls	
Generate Restart Points	Program Controlled
Combined Restart Files	Program Controlled
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	D:\FYP\ANSYS\FYP K Joint Working\FYP K-joint Working_files\dp0\SYS-5\MECH\
Future Analysis	None
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System

TABLE 10
Model (E4) > Static Structural (E5) > Analysis Settings
Step-Specific "Step Controls"

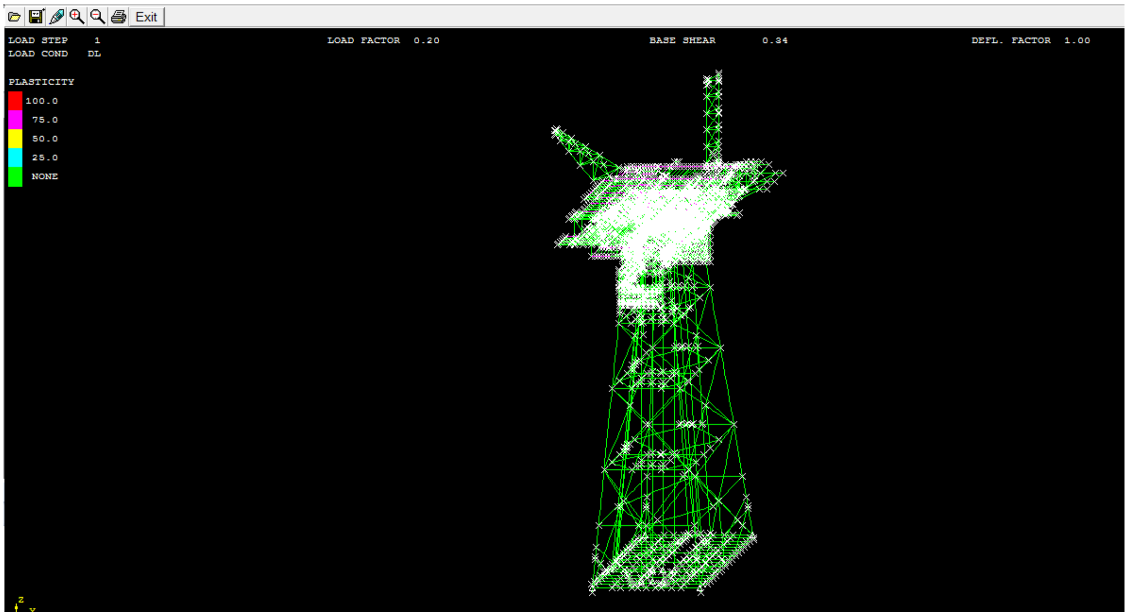
Step	Step End Time
1	1. s
2	2. s
3	3. s
4	4. s
5	5. s
6	6. s
7	7. s
8	8. s
9	9. s
10	10. s
11	11. s
12	12. s
13	13. s
14	14. s
15	15. s
16	16. s
17	17. s
18	18. s
19	19. s
20	20. s

TABLE 11
Model (E4) > Static Structural (E5) > Loads

Object Name	*Fixed Support*	*Force*	*Force 2*	*Force 3*	*Force 4*	*Force 5*	*Force 6*	*Force 7*	*Force 8*	*Force 9*	*Force 10*
State	Fully Defined										
Scope											

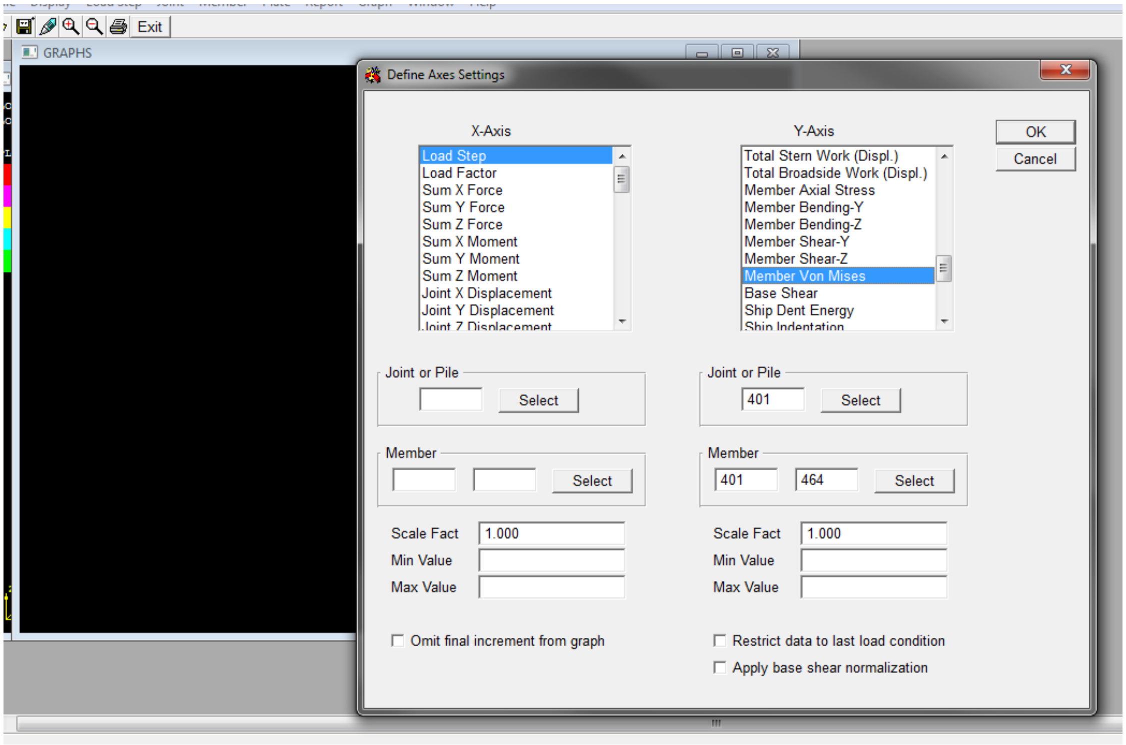
Scoping Method	Geometry Selection
Geometry	1 Face

COLLAPSE ANALYSIS REPORT



```
LOAD STEP    1          LOAD FACTOR  0.20          BASE SHEAR     0.34          DEFL. FACTOR  1.00
LOAD COND   DL

PLASTICITY
  100.0
   75.0
   50.0
   25.0
   NONE
```



Define Axes Settings

X-Axis

Load Step

Joint or Pile:

Member:

Scale Fact: 1.000

Min Value:

Max Value:

☐ Omit final increment from graph

Y-Axis

Member Von Mises

Joint or Pile: 401

Member: 401 464

Scale Fact: 1.000

Min Value:

Max Value:

☐ Restrict data to last load condition

☐ Apply base shear normalization