Radial Interaction for Corrosion Defects in Offshore Pipeline

by

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17681

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32610 Seri Iskandar

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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(CIVIL)

Approved by,

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(Dr Zahiraniza Mustaffa)

UNIVERSITI TEKNOLOGI PETRONAS

SERI ISKANDAR, PERAK

September 2016

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.

NURUL AFIQAH BINTI MOHAMAD ARBA'I

ABSTRACT

Carbon steel pipeline had been trusted as the most reliable and safest way to transmit the fluid from the sources to the consumers. Like any other structural behaviour, this carbon steel tends to fails and require further maintenance after certain period of time. One of the major threats that cause this problem is corrosion activity that acted on the both sides of pipeline wall, internal and external. This affects the pipeline integrity and strength due to the reduction of the wall thickness that caused by metal deterioration.

Throughout this project, the study will be more focused into the defects interaction between external and internal sides of pipeline wall in order to know the defects interaction behaviour radially. Numerical method which is finite element analysis is used as a medium to approach this problem. The research and analysis will be conducted using ANSYS to see the pipeline impact in terms of structure deformation, equivalent elastic strength, equivalent stress and strain energy and etc.

From the finite element modelling generated, the load limit of the pipe is determined based on the maximum von Mises distribution graph plotted. Through comparing predicted failure pressure using proposed solution as well as experimental results in previous literature study, the accuracy of proposed solution is demonstrated consequently.

ACKNOWLEDGEMENT

I would like to express my highest gratitude and praise to God for His blessing and willing, I was able to complete another chapter of my life in the journey of achieving success.

My greatest gratitude to Dr Zahiraniza Mustaffa for her involvement, guidance and helps throughout the project. She ensured that I got a proper understanding regarding the project and always support me from the back whenever I am feeling down. Being under her supervision is totally benefited me. Thank you very much for your understanding over this period.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The application of carbon steel pipelines in oil and gas industry is well known since its early introduction in the industry. As stated by Cosham et al (2007), its combination of good design, materials and operating practices have become a good safety record in oil and gas transportation and transmission. The properties and features owned in addition of the economical factor of the material used has lead the carbon steel for being the biggest contributor in offshore pipeline arena. However, the pipeline tends to be failed after certain period of time like any other structure built.

Being exposed to the rough environment and unstable pressure, the carbon steel pipeline tends to be corroded over time. This problem is occurred due to the electrochemical reaction that lead to the deterioration of metal on pipeline wall (Mustaffa, 2011). It had influenced and triggered the corrosion process acted on the surface longitudinally and circumferentially for internal and external side of the pipeline wall which will reduce the thickness as the time passed.

Usually, the failure pressure of a colony of closely spaced corrosion defects is smaller than the failure pressure that the defects would attain if there were isolated due to the interaction between adjacent defects (Benjamin et al, 2010). In the past of 40 years, the development of a number of study for assessing the defects had been conducted and some of them had been incorporated into industry guidance and recommended practices (Cosham et al, 2007). However, there is no definitive guidance that involved the internal and external side corrosion defects that acted on the pipeline wall.

1.2 Problem Statement

Corrosion is the leading problem that would affect the integrity and operability of the pipeline which in this case referring to carbon steel type. It represents a threat to the overall pipeline strength due to the reduction in the wall thickness (Benjamin et al, 2016). Being exposed to the various type of hazards in the environment and unpredictable flow behavior in the pipeline, the corrosion tends to occur at the external and internal sides of the wall in various shapes and depths. This become a concern since any loss of the pipe wall thickness means a reduction of pipeline structural intensity and hence an increase in the risk of failure (Xu & Cheng, 2012). Besides, it resulted to the lower remaining strength that can be sustain by pipelines which can leads to its failure where the pipeline is leaking or rupture.

The economic consequences of a reduced operating pressure, loss of production due to the downtime, repairs, or replacement can be severe and, in some cases, not affordable (Netto et al, 2005). Due to that, the operability of the pipeline is maintained and allowable strength is determined to ensure the safeness. Metal deterioration problem may occur singly or in colonies, inside and outside of the pipeline. Generally, colonies of corrosion defects that occurred at the both sides of the pipeline wall at the same time will have a high-risk failure to the pressurize pipeline. This problem had reduced the pipe strength as the time passed since the wall become thinner and increased the interaction between defects.

Currently, a number of recommended practices and design codes are developed and published, has been used widely in the industry to determine the remaining strength of the corroded pipeline. However, these 'industry models' are not considering the corrosion that occur at the both sides of pipeline wall. Thus, this research is carry out to come-out with the allowable standard design of the wall thickness when the corrosion defects occur at the both sides of the wall in the same time. This is important so that the pipeline strength can be determined to fit the function until the minimum point of safe working pressure before failure.

1.3 Objectives

The main objectives of the research are;

i. To develop numerical modelling for radial interacting defects of a corroded pipeline
ii. To determine the pipeline minimum remaining strength under safe operation and environment.
iii. To see the interaction of the defects that occur at the internal and external sides of the pipeline wall.

1.4 Scope of Study

Throughout this research, the scope of study will be restricted into few scopes in order to determine the axial spacing design limit of the pipeline based on the interacting defects from both sides of the wall.

The scopes specify are;

- The study is focusing into carbon steel type of pipeline that undergo a metal deterioration on its wall after certain period of time
- Estimation on the corroded area on the pipeline wall to see the variation of the operating pressure allows
- Analysis of minimum allowable pressure acted on the pipeline based on the numerical modelling using ANSYS

CHAPTER 2

LITERATURE REVIEW

2.1 Offshore Pipelines

As stated by Thomson (2006), pipelines play an extremely important role throughout the world as a means of transporting gases and liquids over long distances from their sources to the ultimate consumers. It serves as arteries of oil and gas industry and it had been widely accepted as one of the most economical ways (Chen et al, 2015). Not only that, the ability of the pipeline also had been recognized by the world in transporting the fluid and adapting in various form of environment behaviour.

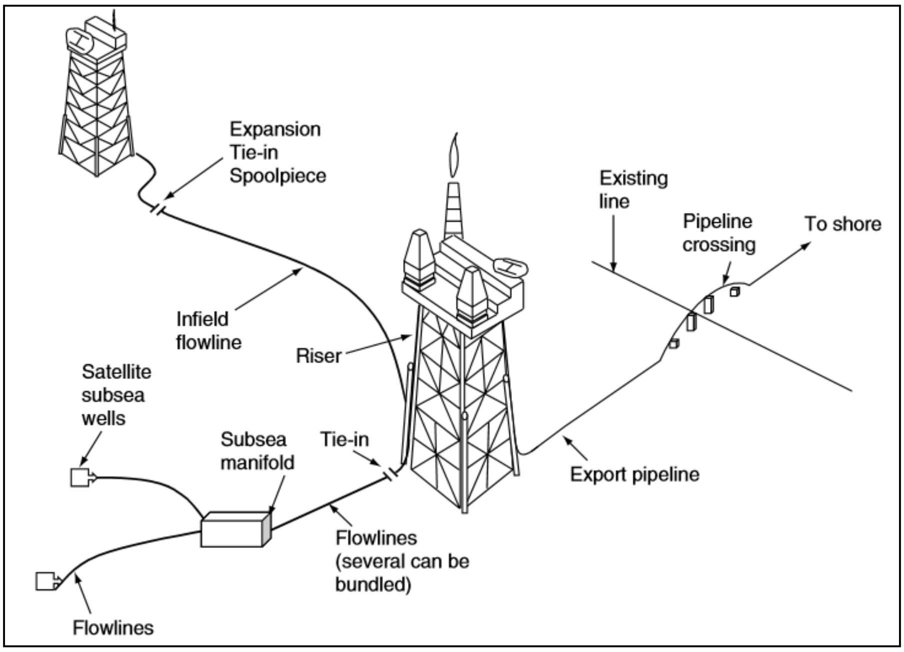


Figure 2.1: Uses of Offshore Pipelines
(Adapted from Guo et al, 2005)

Out of all, carbon steel pipelines are the most preferable types offered due to its good mechanical properties and can be obtained at the low cost compared with other types of pipelines. It can be used where inhibited annual corrosion rate should be put under consideration to the design life in order to cater the problem arises by corrosion activity. Other than that, the carbon steel pipelines need a proper design so that it can be operated safely for a long duration with a minimal maintenance in future.

2.2 Pipeline Hazards

Offshore pipelines system is located at the rough ocean condition that make it susceptible to a lot of uncertainties. Trawling, shipping traffic and anchor, fatigue and buckling are some of the reasons that giving impact to the pipeline which increase its probability to fail.

Based on figure 2.2.2, it indicates how much different mechanism contribute to the overall failure frequency. This can be used to determine how specific features of the pipeline design may affect its operability and at the same time require a further maintenance.

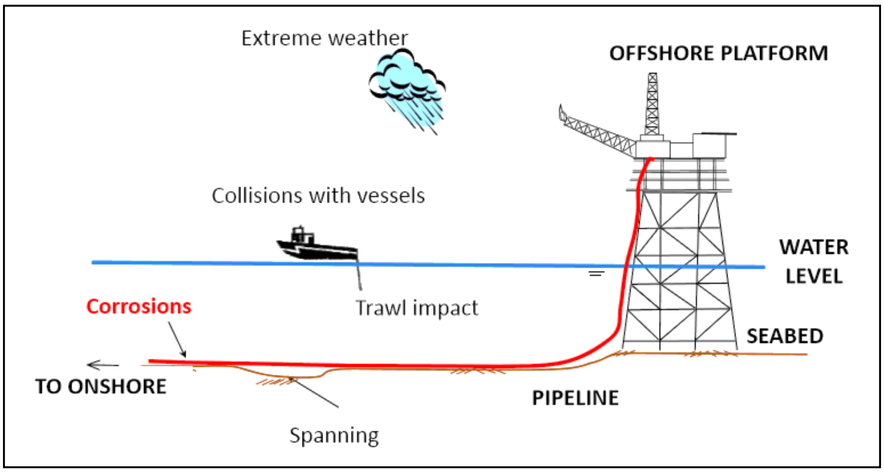


Figure 2.2: Offshore Pipeline Hazards
(Adapted from Mustaffa, 2011)

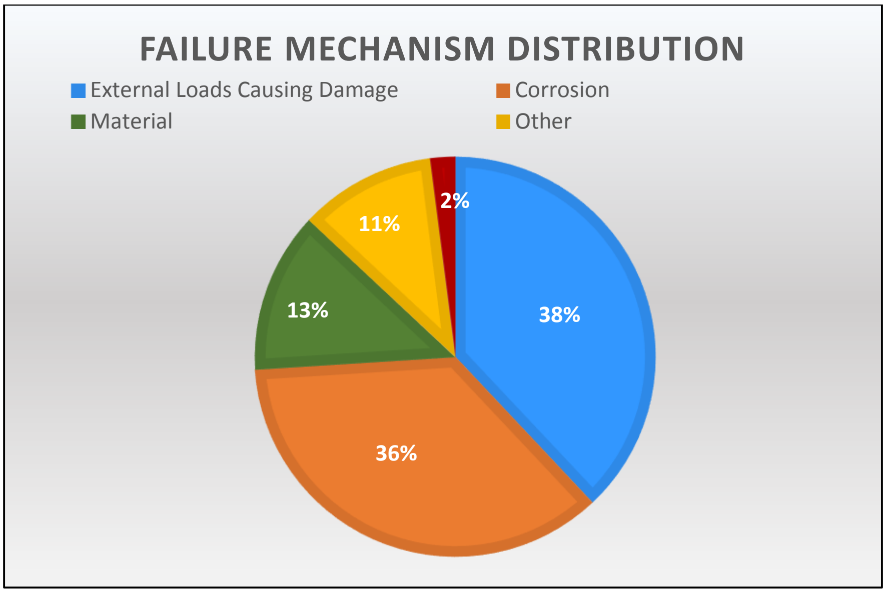


Figure 2.3: Allocation of Failure Mechanisms for Offshore Pipelines
(Adapted & Modified from International Oil & Gas Producers, 2010)

2.3 Corrosion Mechanism

Corrosion is the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces deterioration of the material and its properties (Baboian, 2005). In many cases, the metal loss problem due to the corrosion are frequently found in carbon steel pipelines. One of the reasons is due to the susceptibility of carbon to corrosion which will increase the tendency of the pipeline to be corroded sooner or later after few years of its operability. In general, corrosion can be observed at the internal and external side of the pipeline wall (Mustaffa, 2011).

Corrosion represent a threat to the pipeline strength and integrity because it produces a reduction in the pipe wall thickness (Benjamin et al, 2016). It will become a bigger problem for the pipeline when the internal and external corrosion occurred together.

2.3.1 External Corrosion

According to BS 7910 (2005), this damage mechanism is mainly caused by a wet and dry environmental sequence such as exposure to rain, local environment surrounding the component. Typically, this problem happened where, due to a coating defect or due to the coating degradation, the wet soil enters in contact with the pipe external surface (Benjamin et al, 2016). Its loss from the exposed areas is depending on the material and it can be similar to internal corrosion.

2.3.2 Internal Corrosion

Material loss can take many forms, such as pitting corrosion, crevice corrosion, localised corrosion, general corrosion and mainly due to the contents of the system, including possible impurities (BS 7910, 2005).

All corrosion reactions are electrochemical in nature and depend on the operation of electrochemical (living) cells at the metal surface, which results in different forms of corrosion (Mustaffa, 2011).

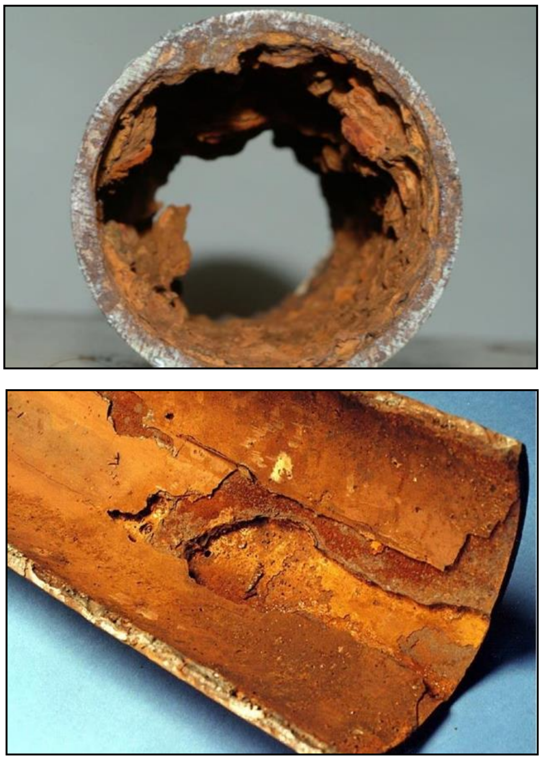


Figure 2.4: Examples of Pipeline Failures due to Internal Corrosion (Adapted from Smith, M., 2014)

2.4 Pipelines Defects

Pipelines defects have its own features and behaviour in order to defined the defects type which usually based on its spacing. It is important to determine since different defects will give a different behaviour of pipeline failures.

2.4.1 Defects Types

Pipelines defects can be described into three types which are, single, interacting and complex defects. Single defect or known as isolated defect is one that does not interact with other defects on the pipeline and the failure pressure acting independently without any influence of other defects.

For interacting defects, it is one that interacts with neighbouring in an axial and circumferential direction. The failure pressure of an interacting defect is lower than it would be if the interacting defects was a single defect, because of the interaction with neighbouring defects (DNV, 2010).

Other than that, based on DNV (2010), there are some cases which complex types of defects occurred that results from combining colonies of interacting defects or a single defect for which a profile is available.

Colonies of corrosion defects are frequently found in the pipelines. Usually the failure pressure of a colony of closely spaced corrosion defects is smaller than the failure pressures that the defects would attained if they were isolated. This reduction in the corroded pipe pressure strength which in the same time increase the degree of complexity is due to the interaction between adjacent defects (Benjamin et al, 2016).

2.4.2 Defects Spacing

In order to define the defects types that occurred on the pipe, there is a few measurements (refer to spacing/separation between defects) need to be identify as a part of requirement.

Longitudinal Spacing : Defined by the distance between the corrosion defects that located axially which the metal deterioration occurred along the pipe together to each other (longitudinally aligned).

Circumferential Spacing : Distance between the defects that occurred on the opposite axis around the circular shaped of the pipe.

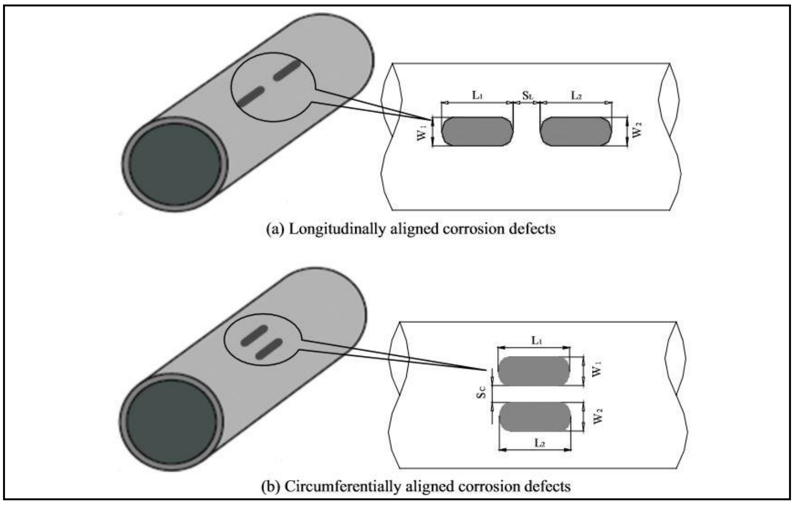


Figure 2.5: Schematic of Pipeline with Interacting Corrosion Defects (Adapted from Chen et al, 2015)

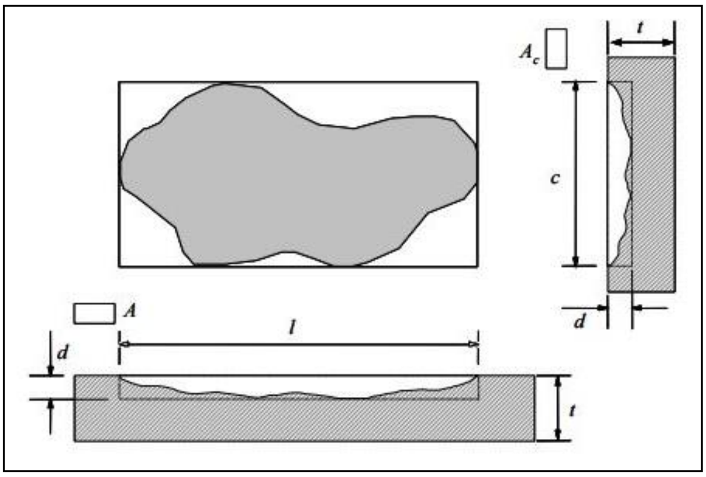


Figure 2.6: Single Defect Dimensions
(Adapted from DNV, 2010)

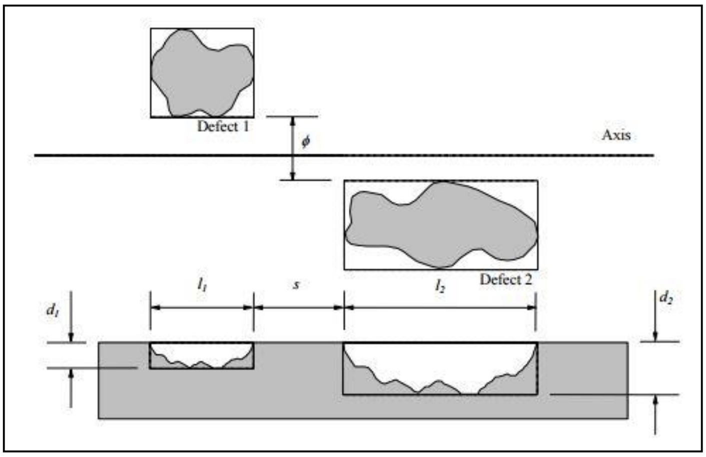


Figure 2.7: Interacting Defect Dimensions
(Adapted from DNV, 2010)

2.5 Design Codes and Recommended Practices

2.5.1 DNV Recommended Practices (DNV RP F101)

DNV Recommended Practices or more specifically refer to DNV RP F101 has successfully being used in many projects for the corroded pipeline assessment. Being introduced and issued on 1999, this recommended practices includes the recommendations for the assessment of; single defects; interaction defects, complex shaped defects and additional external loading that describes two alternative approaches with different safety philosophy (Bjørnøy, Sigurdsson, & Marley, 2001).

Bjørnøy et al. (2001) also describes that the first approach is by includes the calibrated safety factors, taking into account the natural spread in material properties and wall thickness and internal pressure variations. For second approach, it is based on the allowable operating pressure design format, where the allowable operating pressure is determined from the capacity and multiplied with a single usage factor based on the original design factor.

2.5.2 The American Petroleum Institute Recommended Practices 579 (API 579)

Fitness-for-service (FFS) assessments are quantitative engineering evaluations, which are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. The API 579 has been developed to provide guidance for conducting FFS assessments of laws commonly encountered in the refining and petrochemical industry which occur in pressure vessels, piping, and tankage (Anderson & Osage, 2000).

Anderson and Osage (2000) also stated that the API 579 is intended to supplement and augment the requirements in API 510, API 570, and API 653 in order to ensure safety of plant personnel and the public while other equipment continues to operate; to provide technically sound FFS assessment procedures; to ensure that different service providers furnish consistent remaining life predictions; and to help optimize maintenance and operation of existing facilities to maintain availability of older plants and enhance a long-term economic viability.

2.5.3 British Standard 7910 (BS 7910)

BS 7910, the UK procedure for the assessment of flaws in metallic structures that had been introduced since 1980 (Hadley, 2009). It was published in the form of a fracture/fatigue assessment procedure that providing the basis for analysing fabrication flaws and the need for repair in a rational fashion.

Since from the first publication, BS 7910 has been regularly maintained and expanded, taking in elements of other publications, assessment procedure and the gas transmission industry's approach to assess of locally tinned areas in pipelines.

2.5.4 Kiefner and Vieth / Modified RSTRENG

Acts to devise a modified criterion that, while still assuring adequate pipeline integrity, would eliminate as much as possible the excess conservatism embodied in the existing criterion (referring to B31G). The proposed modified criterion presented is less conservative than the existing B31G criterion. It will permit metal-loss anomalies of greater size to remain in service at the current maximum operating pressure. And, for anomalies which exceed the newly recommended allowable size, the modified criterion will require less pressure reduction to maintain an adequate margin of safety for all cases (Kiefner & Vieth, 1989).

2.5.5 Pipeline Operator Forum

Pipeline Operator Forum or shortly being defined by POF is a non-profit forum enabling pipeline inspection and integrity engineers to share and build good practices, with the ultimate purpose of improving the quality of pipeline integrity management at every level, hence protecting people, the environment and operational integrity of pipelines globally (POF, 2016).

Being joined by a large number of big player in oil and gas industry, they are providing a number of specification and guidelines that mainly focused on intelligent pig inspection of pipeline, in-line-inspection first run and corrosion resistant alloy pipelines integrity management.

Proposition of Interaction	Longitudinal Limit	Circumferential Limit
DNV RP F101	$2.0\sqrt{Dt}$	$\pi\sqrt{Dt}$
API 579	$(L_1 + L_2)/2$	$(w_1 + w_2)/2$
BS 7910	$2.0\sqrt{Dt}$	$3\sqrt{Dt}$
Kiefner and Vieth	$25.4\ mm$	$6t$
Pipeline Operator Forum	$min(6t, L_1, L_2)$	$min(6t, w_1, w_2)$

Table 2.1: Summary of Interaction Rules
(Adapted & Modified from X. Li et al, 2016)

2.7 Finite Element Analysis

The development and validation of new assessment methods for the pipeline with corrosion defects have been based on results of both laboratory tests and finite element analyses from the beginning of the 1990s (X. Li et al, 2016). It is a powerful numerical tool that can be used to study the colonies of corrosion defects failure behaviour.

In number of research for many years, ANSYS, a well-known general purpose finite element program is being used to conduct the finite element analyses widely for structural such as buckling and non-structural cases like heat transfer and fluid flow. Its capabilities had enables the researchers to analyse their case study in linear and non-linear way in a shorter duration at a lower cost.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In this section, the method and process execution plan are explained to offer the theoretical underpinning for understanding which method, state of method, or so called "best practices" can be applied throughout this research.

According to Silva, Guerreiro & Loula (2007), from the study that had been conducted, multiple corrosion defects are supposed to interact when they lead to a failure pressure lower than the occurring in pipes with individual or single defects. In this sense, the failure pressure tends to be lowest if the interacting defects occur at both sides, internal and external of the pipeline wall.

Thus, in this study, numerical modelling will be conduct to see the pressure impact acting on the pipeline wall at the presence of both internal and external defects at the pipeline wall.

3.2 Numerical Method

This assessment is conducted to determine whether the pipeline is fit for the intended operating pressure or need to be repaired by estimating the remaining strength of the corroded pipeline.

In order to achieve the objective of the research, ANSYS software was used as a main tool for the physical and geometric non-linear analysis of the structure behavior to obtain the failure pressure value. The numerical results obtain from the automatic generic models will be analyzed to see the radial interaction between the defects.

For this research, static structural analysis is chosen to perform the simulation of the pipe structure under internal static loads. Figure 3.1 – Figure 3.10 shows the procedure of the numerical modelling using ANSYS.

3.2.1 Pipeline Stresses and Load Identification

Identification of stresses and loads are important to be known at the early stage of the experiment. This is due to their influence in predicting the corroded pipeline failure. The pressure classification is also important to be decide as a parameter throughout the study. In this research, the pressure was only acted on the internal surface of the model.

3.2.2 Validation of Finite Element Modelling

Validation and comparison are crucial and necessary to be conducted to see the accuracy and the differences between the results obtained from the numerical modelling and the available information in the current research paper. Thus, this stage is conducted to ensure the simulation is valid to be used throughout this research.

3.2.3 Corroded Pipeline Modelling

Modelling of corroded pipeline using finite element method allow the wide range of analysis involving various shapes of model in various material behaviour. The ANSYS software allows the user to simulate the critical area (where it is expected to fail) and to simulate the deforming surfaces. Its multiphysics capabilities had enable the user to improve the innovation and performance in a shorter duration.

i. Geometrical Modelling

Hollow cylindrical modelling that define the stiffness of the material used for the pipeline model. For this research, the corroded pipeline is modelled by using Solidworks before exporting it into ANSYS for numerical modelling.

ii. Material Properties

All the material properties data required are defined based on API 5L X80 offshore pipeline features (referring to Modulus of Elasticity, Poisson’s Ratio, Yielding and Ultimate Tensile Strength).

iii. Meshing

Meshing in general is a geometry discrete representation that is involved in partial differential equations for computational solutions (in this case, referring to ANSYS). It is a method of representing field variables such as displacement by polynomial function that is compatible with boundary condition defined.

iv. Selection of Load and Boundary Condition

The load assigned is acting on the internal side of pipeline wall as a representation of internal pressure loading subjected to pipeline. The magnitude of load is varied throughout this study in order to find the maximum pressure that the pipeline can sustain before fail based on several defects location specified. As stated by X. Li et al (2016), the boundary condition effect can be ignored as long as the length of the pipe is larger than four times the diameter of the pipe. Thus, the appropriate boundary condition is selected in the simulation which is fixed condition at the both end of the pipe.

v. Data Analysis & Interpretation

Interpretation and analysis of the results generated by ANSYS consist of deformation, equivalent elastic strain, and equivalent stress. From there, the interpretation of result was conducted to identify the maximum failure pressure allowed for different types of corrosion configuration. It is determined by adopting "ligament stress criterion" that stated that the failure approaches equivalent stress when the minimum ligament is exceeding the true ultimate tensile strength of the material.

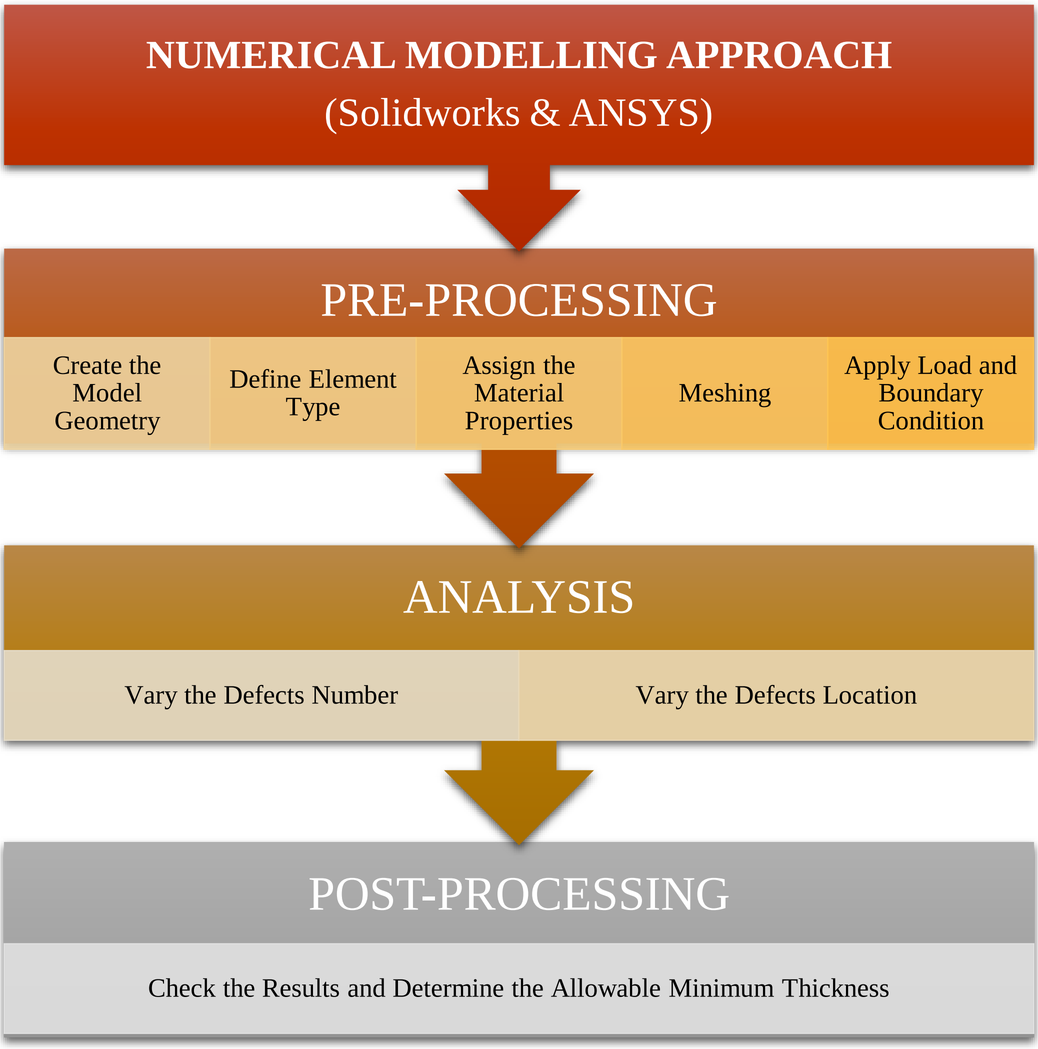


Figure 3.1: Schematic Flow of Numerical Modelling

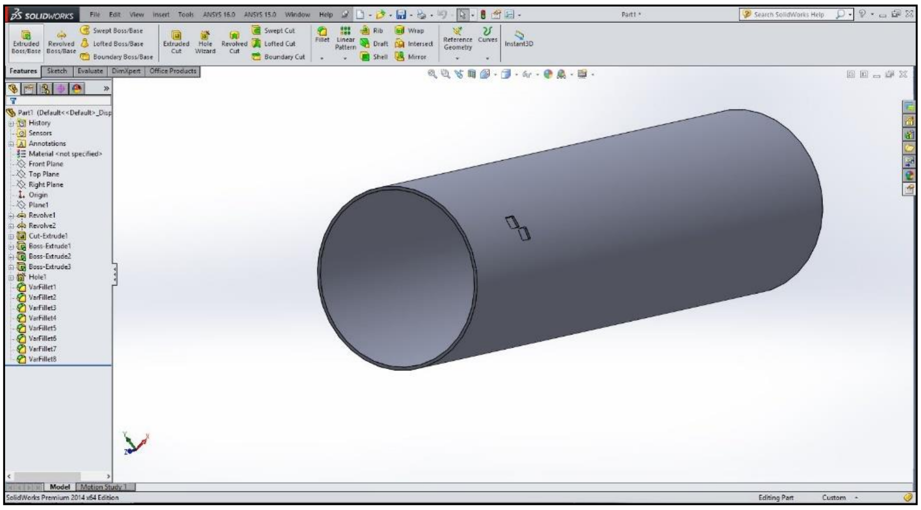


Figure 3.2: Pipeline Model Using Solidworks

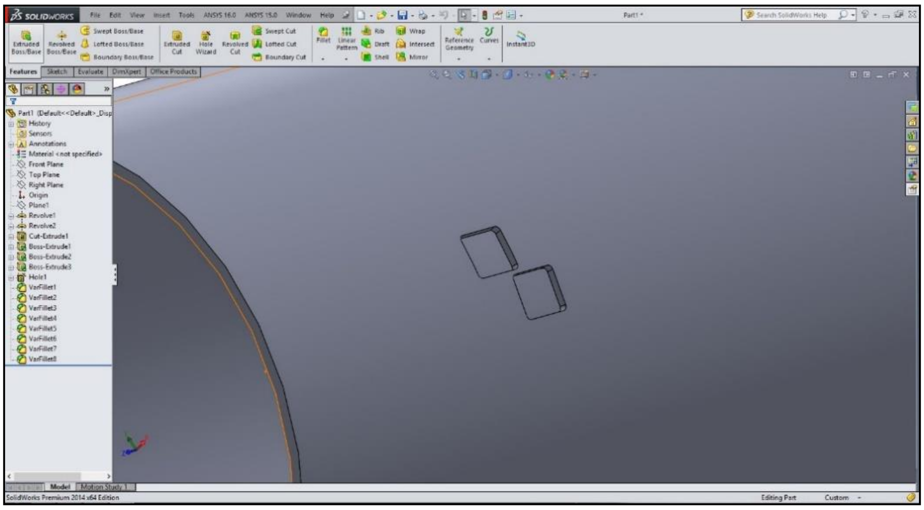


Figure 3.3: Pipeline Corrosion Defects Model Using Solidworks

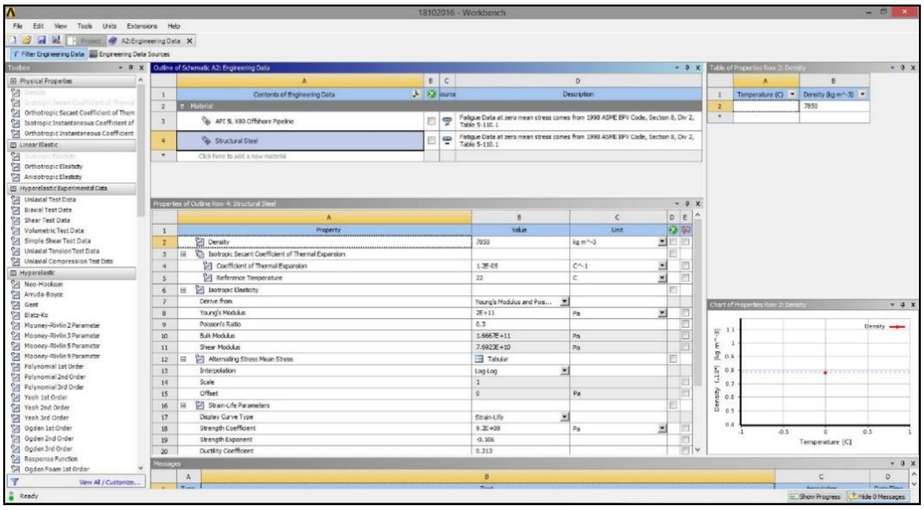


Figure 3.4: Defining the Material Properties for Static Structural Analysis

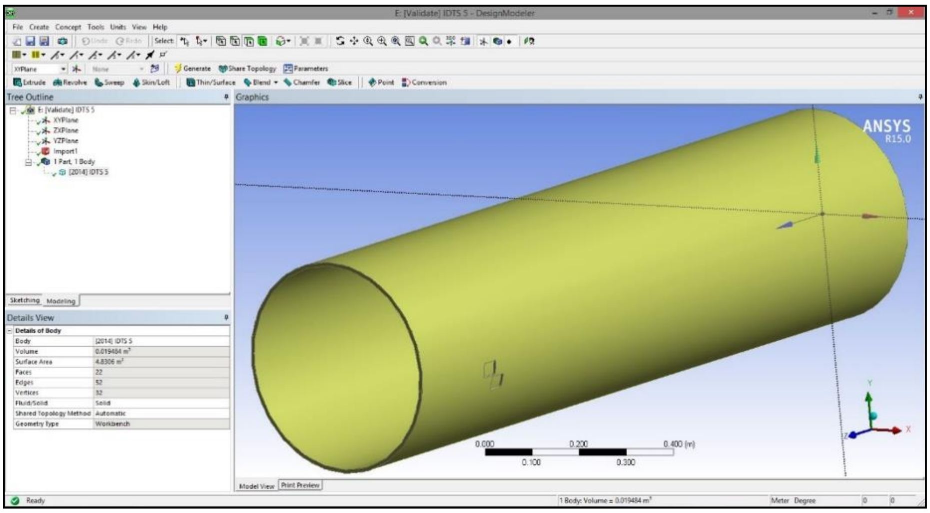


Figure 3.5: Importing the Geometry into Workbench

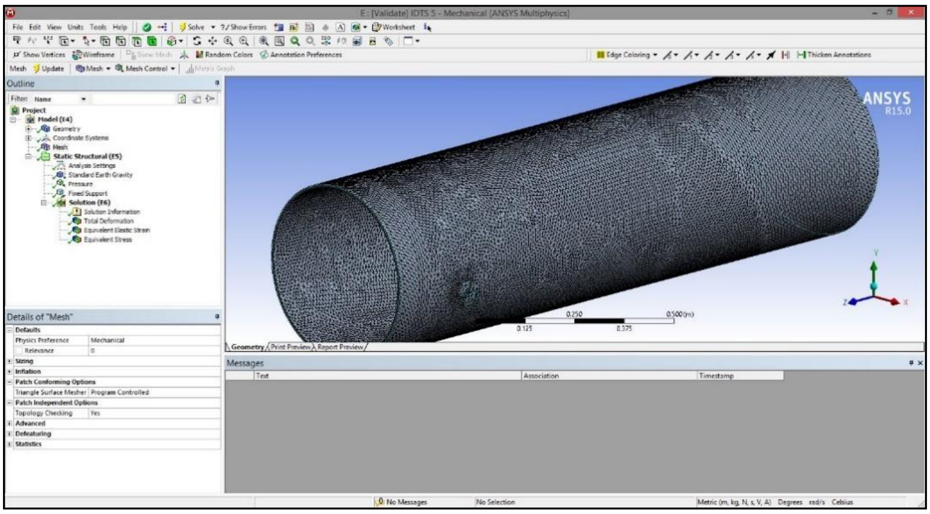


Figure 3.6: Meshing

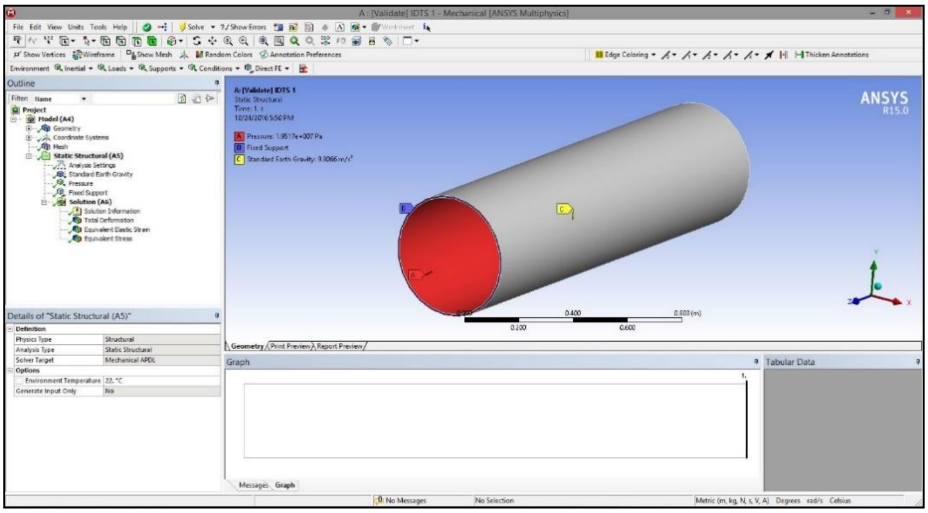


Figure 3.7: Defining the Acted Loads and Boundary Condition

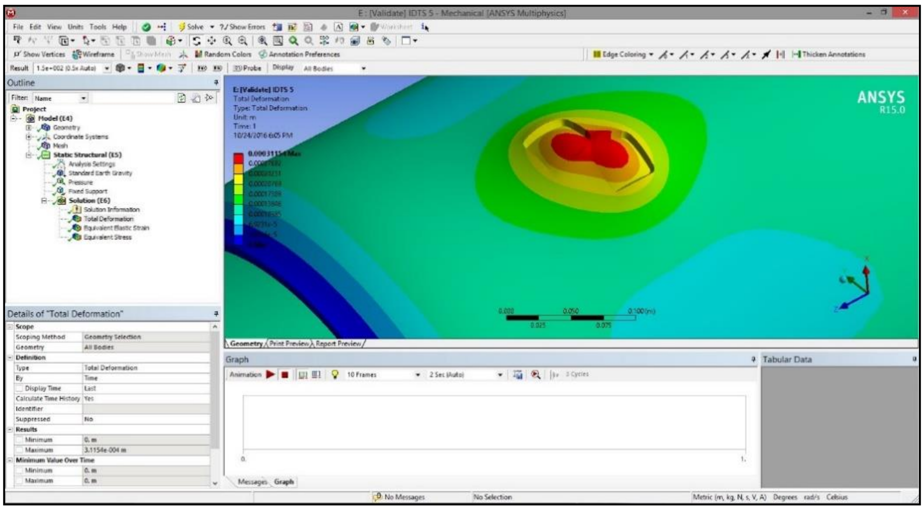


Figure 3.8: Result on Total Deformation

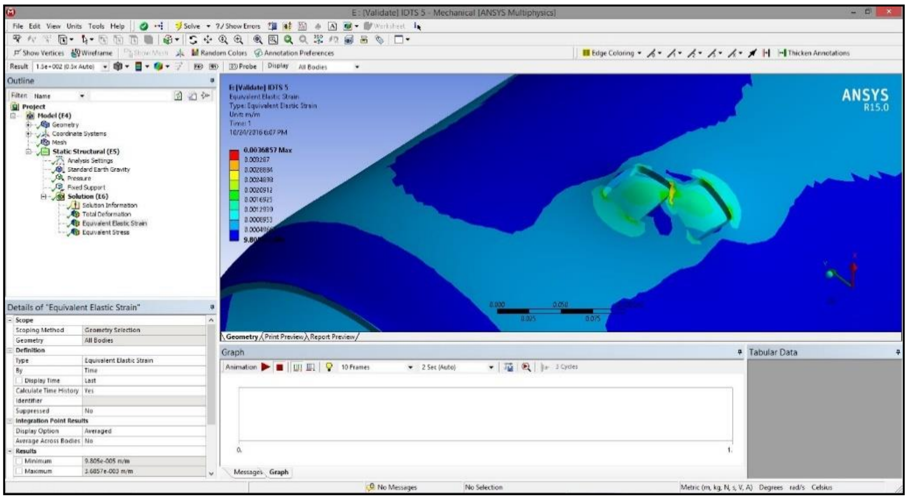


Figure 3.9: Result on Equivalent Elastic Strain

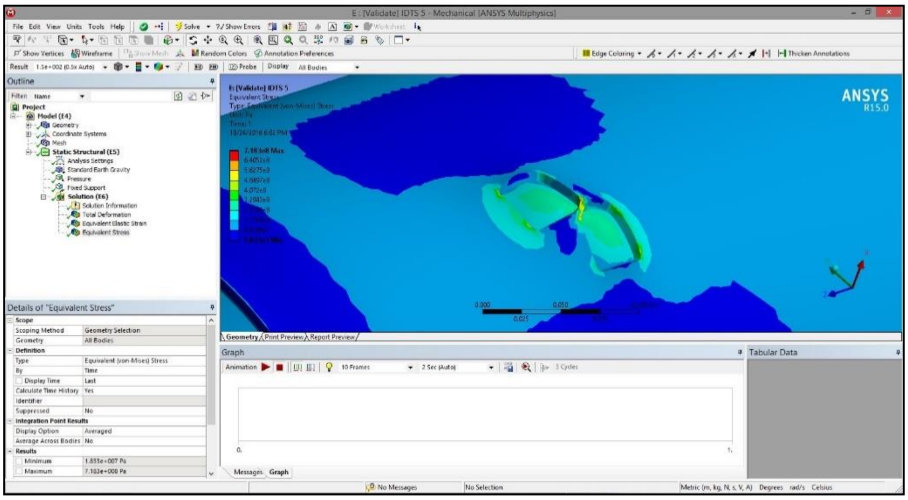


Figure 3.10: Result on Equivalent Stress

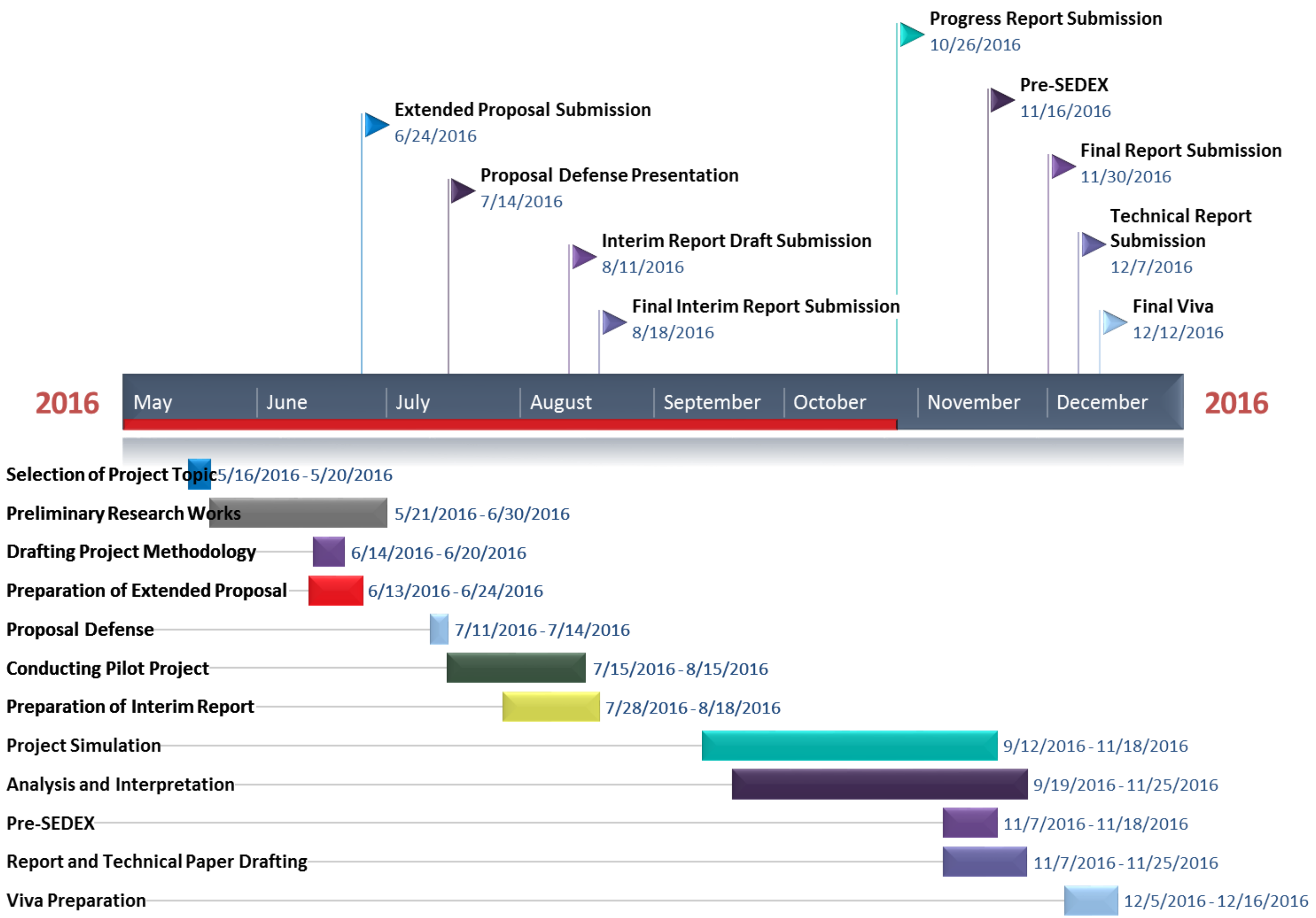
3.3 Properties of Pipeline Modelled

All specimens of corroded pipe are constructed in ANSYS based on physical and mechanical properties stated below. The parameters listed are important to be defined since they play a significance role to determine the failure behaviour of the pipe.

Parameters	Unit	Dimension
Outside Diameter	mm	458.80
Wall Thickness	mm	8.10
External Defect Depth	mm	3.24
Line pipe Grade		API 5L X80
Length	mm	1700
Steel Density	kg/m^3	7850
Specified Minimum Yield Strength	MPa	552
Specified Minimum Tensile Strength	MPa	621
Ultimate Tensile Strength	MPa	661
Elastic Modulus	N/mm^2	200000
Poisson Ratio		0.3

Table 3.1: Pipeline Properties

3.4 Project Milestone



3.5 Project Timeline

No	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Decide on Report Structure	■	■												
3	Preliminary Research Work		■	■	■										
4	Study on Research Parameters		■	■	■										
5	Submission of Extended Proposal					■									
6	Proposal Defend Preparation						■	■							
7	Proposal Defend								■	■					
8	Submission of Draft Interim Report										■	■			
9	Submission of Interim Report												■	■	■

Table 3.2: FYP I Project Timeline

No	Activities	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Simulation	■	■	■	■	■	■	■	■	■	■				
2	Data Analysis		■	■	■	■	■	■	■	■	■	■			
3	Result Interpretation							■	■	■	■	■			
4	Project Discussion										■	■	■		
5	Pre-SEDEX Preparation									■	■				
6	Report Drafting									■	■	■			
7	Submission of Technical Paper												■	■	
8	Preparation for Oral Presentation													■	■
9	Submission of Project Dissertation														■

Table 3.3: FYP II Project Timeline

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Finite Element Modelling Validation

The numerical simulation was validated to ensure its accuracy since it was highly dependent on the features used in the generation of the model. Based on the previous research that had been done by Benjamin et al (2011), the experimental results were compared with the value generated from finite element modelling by using the same case of pipe.

There are four defects configurations simulated based on Mixed Type Interaction (MTI) database that was developed by oil and gas joint industry in 2011. From there, the result obtained were compared with the experimental results done by the authors and the best choice of non-linear finite element modelling was then decided. The corrosion profile and the failure pressure of the pipe are briefly explained in the table below.

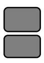
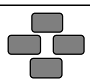
Case	Defect Depth (mm)	Corrosion Profile						Failure Pressure	
		Corrosion View	*L* (mm)	*w* (mm)	R (mm)	S_L (mm)	S_C (mm)	P-Test (MPa)	P-FEM (MPa)
IDTS 2	5.39		39.60	31.90	3.50	0.00	0.00	22.68	**21.03**
IDTS 3	5.32		39.60	31.90	3.50	20.50	-31.90	20.31	**17.94**
IDTS 4	5.62		39.60	32.00	3.50	-39.60	9.90	21.14	**20.21**
IDTS 6	5.39		39.60	32.20	3.50	20.50	9.60	18.66	**16.95**

Table 4.1: Comparison of FEM Results and Measured Failure Pressure

By following the details specified, all the results generated from the simulation are plotted in the graph below to see the trendline of the failure pressure between experimental test and finite element modelling.

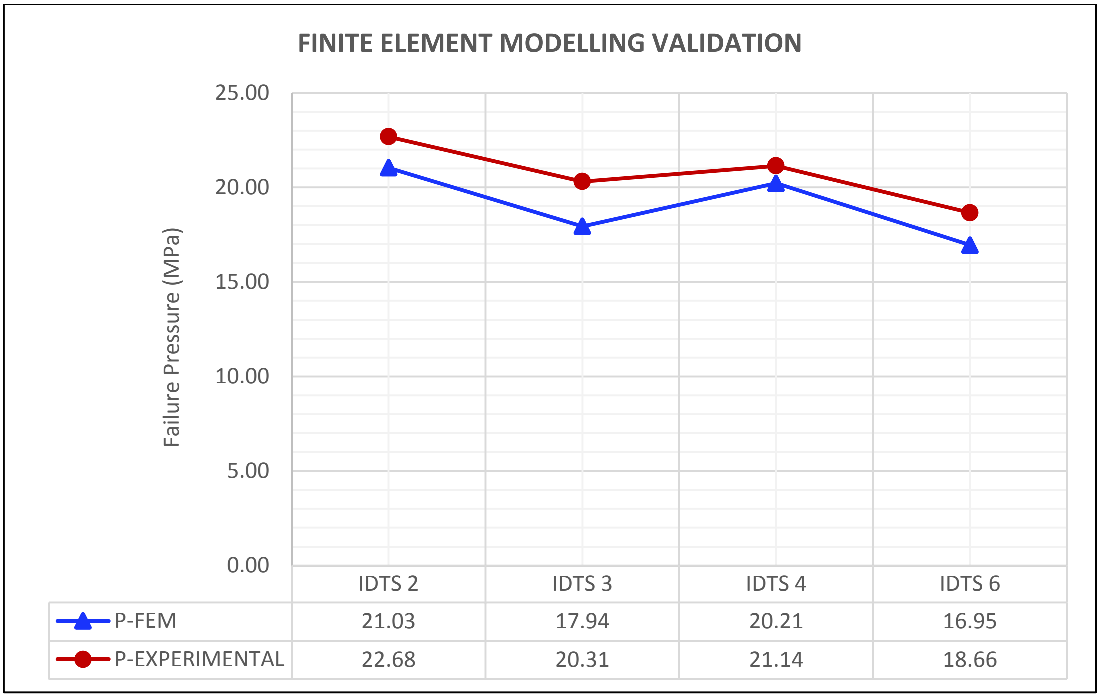


Figure 4.1: Comparison of FEM Results and Measured Failure Pressure

Based on the graph shown above, the percentage error for each of the corrosion configuration are less than 10% based on all four samples of the corroded pipe modelled. Therefore, it is concluded that the developed simulation model is valid to be conducted to the next stage of study. This is due to its ability in predicting the deformation and failure pressure of the specimens.

4.2 Corroded Pipe Assessment

The simulations were performed with 24 tubular specimens which were loaded with internal pressure only with different defect configurations at different location of the internal side corrosion defects. Table 4.2 shows the dimensions of the defects with the longitudinal spacing and circumferential spacing between defects respectively.

By fixing the defects occurred at the external sides of the pipeline wall, the results are determined and plotted by varying the defects depth and location at the internal side as shown in Figure 4.2.

Defect Location	Defect Depth (mm)		Corrosion Profile					
			Corrosion View	L (mm)	w (mm)	R (mm)	S_L (mm)	S_C (mm)
Longitudinally Alligned								
External	40%	3.24		39.60	31.90	3.50	121.92	0.00
Internal	10%	0.81		39.60	31.90	3.50	0.00	0.00
	20%	1.62		39.60	31.90	3.50	0.00	0.00
	30%	2.43		39.60	31.90	3.50	0.00	0.00
	40%	3.24		39.60	31.90	3.50	0.00	0.00
Circumferentially Alligned								
External	40%	3.24		39.60	31.90	3.50	0.00	191.52
Internal	10%	0.81		39.60	31.90	3.50	0.00	0.00
	20%	1.62		39.60	31.90	3.50	0.00	0.00
	30%	2.43		39.60	31.90	3.50	0.00	0.00
	40%	3.24		39.60	31.90	3.50	0.00	0.00

Table 4.2: Corroded Defects Configurations

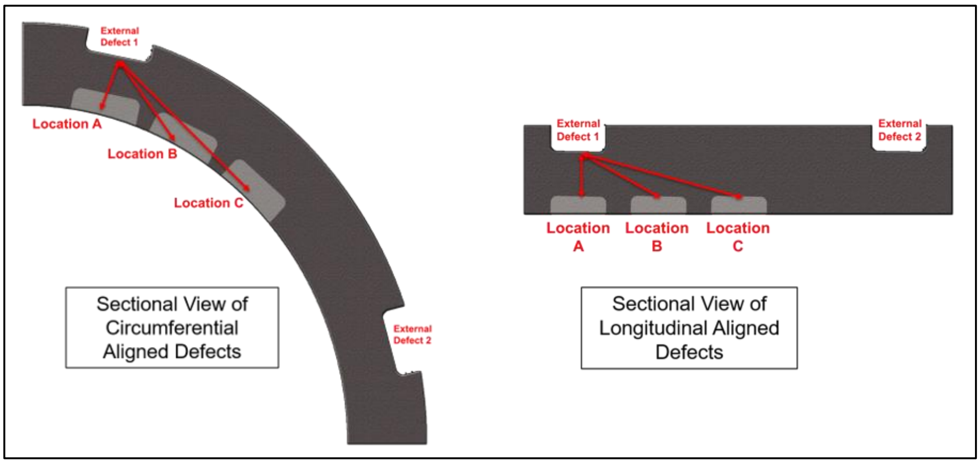


Figure 4.2: Location of Corroded Defects at External and Internal Sides of Pipeline Wall

4.2.1 Variation of Internal Defect Depth (Longitudinal Aligned Defects)

Figures below shows the maximum von Mises distribution for longitudinal aligned defects case for different internal defects depth. This parameter is variated to see its influence on radial interaction between defects located at the external and internal sides of pipeline wall longitudinally.

The internal defect depth is ranging from 10% to 40% and different internal loadings are simulated to see its corresponding to the maximum von Mises stress distribution.

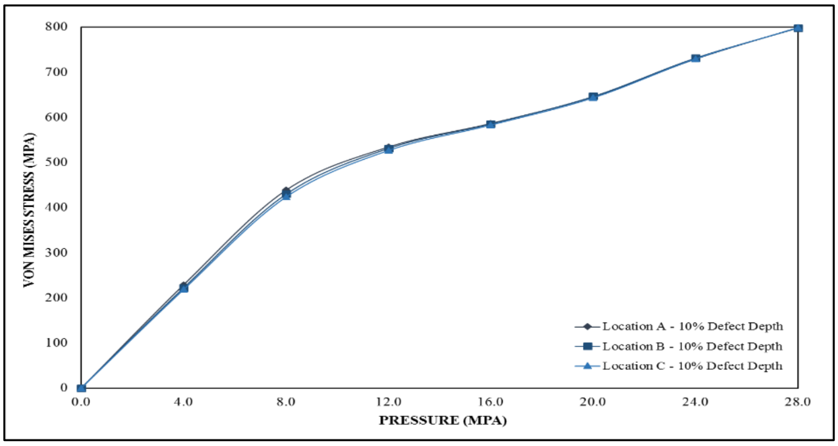


Figure 4.3: Longitudinal Aligned – 10% Internal Defect Depth

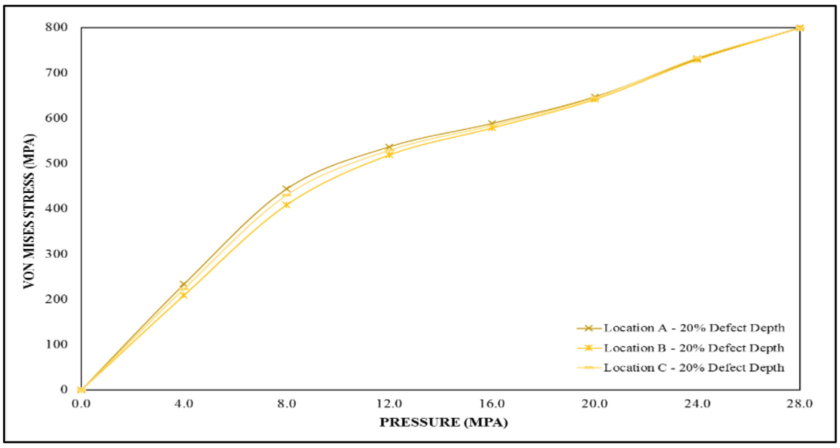


Figure 4.4: Longitudinal Aligned – 20% Internal Defect Depth

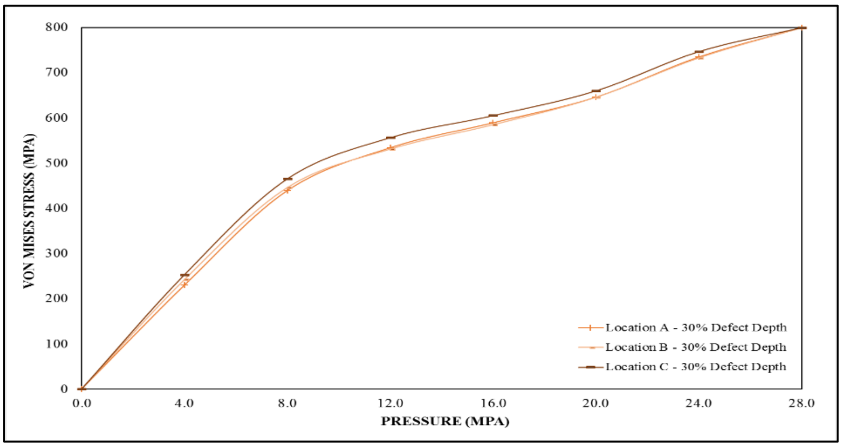


Figure 4.5: Longitudinal Aligned – 30% Internal Defect Depth

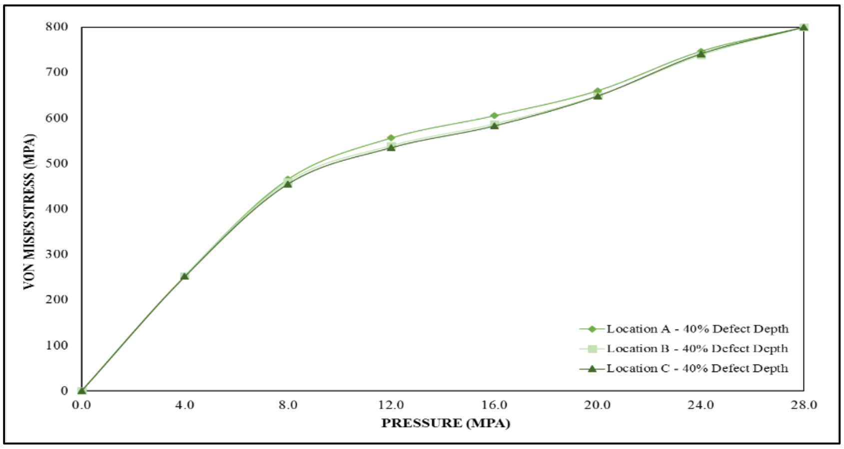


Figure 4.6: Longitudinal Aligned – 40% Internal Defect Depth

4.2.2 Variation of Internal Defect Depth (Circumferential Aligned Defects)

Since the simulations are conducted for two different cases, longitudinal and circumferential aligned defects, the same procedure is carried out for circumferential aligned defects case to see the defects interaction.

Figure 4.7 – Figure 4.10 shows the distribution of maximum von Mises stress under different pressure acted on the internal wall when the external and internal defects located circumferentially.

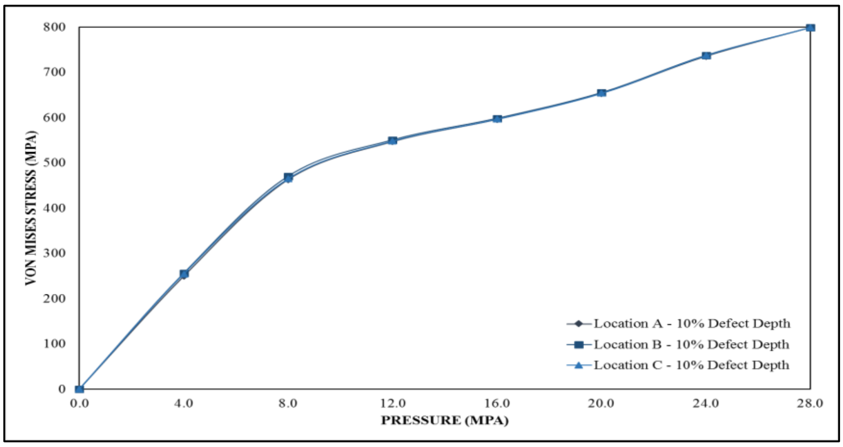


Figure 4.7: Circumferential Aligned – 10% Internal Defect Depth

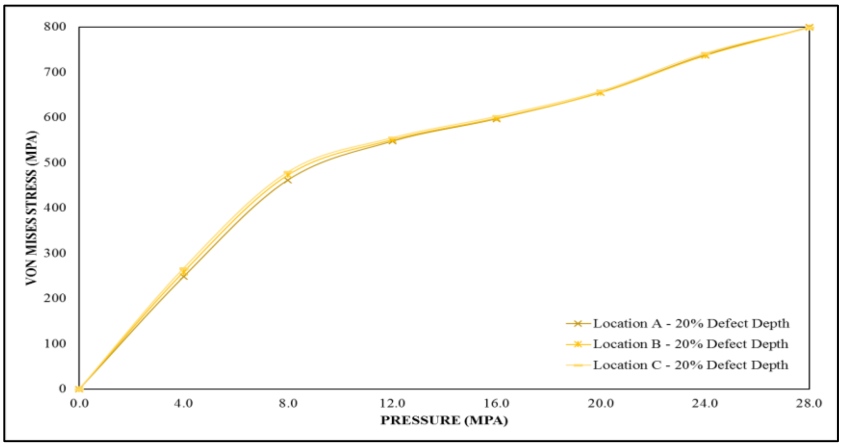


Figure 4.8: Circumferential Aligned – 20% Internal Defect Depth

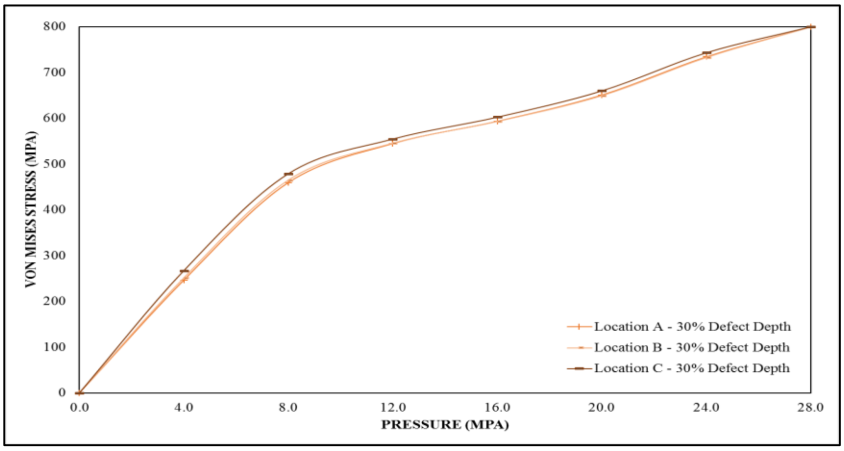


Figure 4.9: Circumferential Aligned – 30% Internal Defect Depth

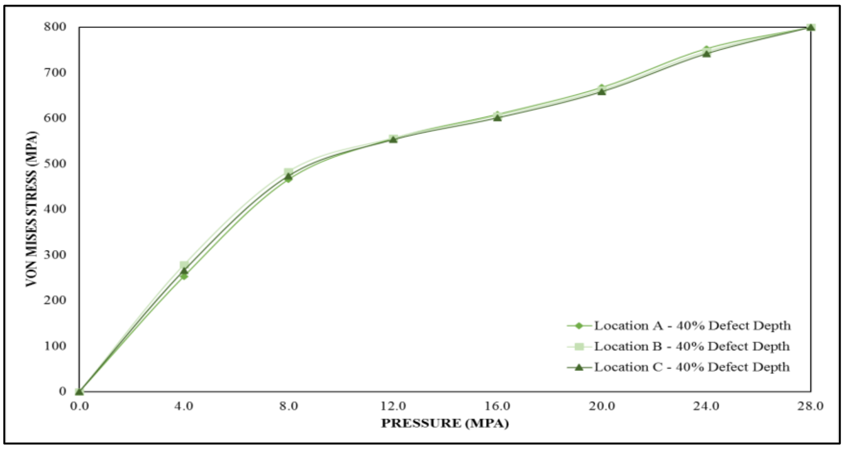


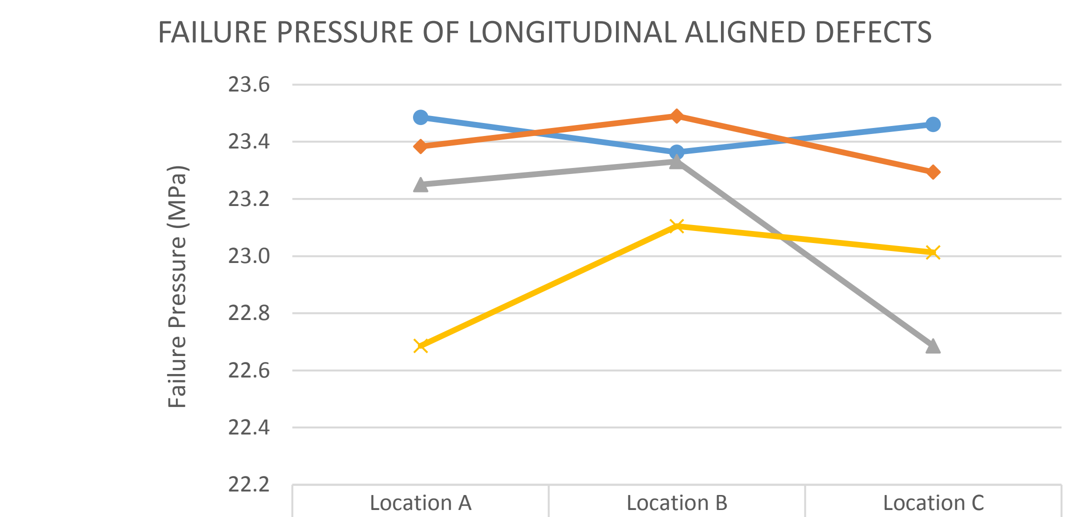
Figure 4.10: Circumferential Aligned – 40% Internal Defect Depth

To determine the failure pressure associated with internal pressure, graph of maximum von Mises stress versus internal pressure were plotted for longitudinal aligned defects and circumferential aligned defects case. The analysis was conducted on a 458.8mm diameter pipeline of API 5L X80 with 8.1mm of wall thickness. At a different depth and location, the results are plotted as per seen above for different aligned defects case.

The graphs above show the von Mises increment with respect to internal pressure acting on the pipeline wall. From there, the failure pressure is determined for each of the specimen that having a different configuration of the defects. By adopting the ligament stress criterion, the pressure limit of the selected sample is obtained from the projection of the true ultimate stress of the pipe which is for this case is 718.2 MPa at the von Mises stress axis.

4.3 Failure Pressure of the Corroded Pipe

The failure pressure of the corroded pipe is determined based on the maximum von Mises graph generated previously and plotted below to see the trendline of the specimens. For both aligned defects case, longitudinal and circumferential, different internal defects depth resulted to lowest failure pressure at different location.

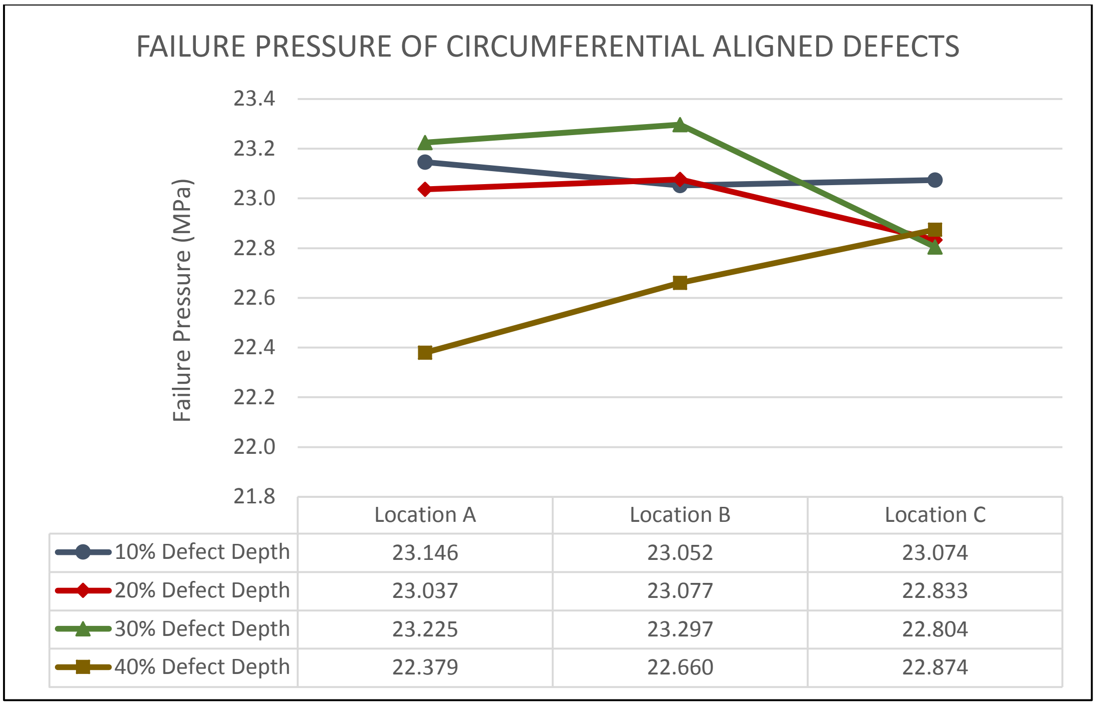


	Location A	Location B	Location C
10% Defect Depth	23.486	23.363	23.461
20% Defect Depth	23.384	23.490	23.294
30% Defect Depth	23.250	23.331	22.686
40% Defect Depth	22.686	23.105	23.013

Figure 4.11: Failure Pressure at Different Location for Longitudinal Aligned Defects

Figure 4.11 represents the generalised data of varying the defects depth and location at the internal side of the pipeline wall for longitudinal aligned cases.

For 10% defect depth, the lowest failure pressure is occurred when the defect at the internal sides of the wall located at location B, but different case when the defect depth is increased to 20% and 30% where the location C caused to be the lowest failure pressure allowed to act on it due to the interaction between both of defects at the external sides of the wall at the same time. As the depth increase to 40%, the lowest failure pressure for the pipe is at the location A due to the major metal loss at that particular area which reduce its withstand ability.



	Location A	Location B	Location C
10% Defect Depth	23.146	23.052	23.074
20% Defect Depth	23.037	23.077	22.833
30% Defect Depth	23.225	23.297	22.804
40% Defect Depth	22.379	22.660	22.874

Figure 4.12: Failure Pressure at Different Location for Circumferential Aligned Defects

Figure above represent the generalised data of varying the defects depth and location at the internal side of the pipeline wall for circumferential aligned cases.

From the graph plotted, the corresponding result are same like longitudinal aligned defects simulation. The lowest failure pressure occur are not focusing at one particular location for all case but variate as the defect depth increase. For 10% defect depth, the lowest failure pressure for internal defect located at Location B, while for 20% and 30%, located at Location C and lastly for 40% internal side defect depth, the lowest failure pressure occurred when the internal and external sides defects are overlapping to each other at Location A.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

From the result, it is shown that the simulation conducted has meet the objectives of the study. The simulation is performed based on the location of the defects at the internal side of the pipeline wall and its depth ranging from 10% until 40% from the total of the wall thickness.

Based on the discussion on the result of the maximum von Mises stress distribution which obtained from the finite element modelling, it is concluded that the stress is increasing as the internal pressure acted on the pipeline increase. From the result plotted, the failure pressure is determined based on ligament-stress criterion adopted.

The lowest failure pressure allowed for each of the pipe sample are depends on the defects depth at the internal sides of the wall and its location. Different depth resulted to different crucial area of the defects for longitudinal and circumferential aligned cases.

- Location A is the most crucial area when the defects depth at the internal side of the wall are 40% from the total wall thickness which is at the same time cause by the major metal loss due to the overlapping defect that located at the external sides of the wall.

- Different case happened when the defects at the internal side of pipe are too small which is 10% of the wall thickness where the most dangerous area that need to be taking care of is at the Location B.

- For Location C, even though the overlapping is not occurred and it is the furthest spacing compared with Location A and B, but the interactions occur between both defects at the external sides of the wall caused the location to be the highest tendency to fail when 20% - 30% of the metal loss occurred at the internal sides of the pipe.

5.2 Recommendation

5.2.1 Recommendation for future work

From the study, some suggestions are recommended to enhance the significance of the expected results towards determining the radial defects interaction of the offshore pipeline. The recommendations for future study are as following:

- Refinement of meshing on the critical area of defects. The discretization errors will be reduced with mesh refinement.
- Wider scope and range of defects location at the internal side of pipeline so that the proper interaction study between the defects can be produced.
- Different shape and dimension of the defects in order to see the factors that influence the failure behaviour of the pipe.

5.2.2 Recommendation for expansion work

Radial interaction defects are a wide area subject to be researched for. Thus, below is several more areas to be studied such as:

- Different pipeline grade
  To reduce the existing conservatism in the existing pipe standards when it comes to the assessment of interacting defects. By varying the grade, the results obtained in determining the interaction are more accurate as a whole.

- Validation through experimental works
  This program need to be carry out in future to further validate the work presented in this project.

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