Risk Assessment and Integrity Analysis of Flexible Subsea Pipeline in Indonesia

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Abstract. As an oil and gas producing country, Indonesia has oil and gas fields located both onshore and offshore. To transport hydrocarbon fluids safely, the pipeline must be able to respond to the challenges especially in a subsea operation which are high risk, high cost, and high technology. To face these challenges, flexible pipe has become one of the solutions and it is necessary to conduct a risk-based assessment and integrity analysis. In this study, the integrity assessment of flexible pipeline will be conducted by utilizing Muhlbauer's Index Method, and Quantitative Risk Based Inspection (QRBI) approach with several adjustments. The probability of failure is obtained based on the potential damage mechanisms according to the interaction between the flexible pipe material, the transported fluid, and the environment. As the result, an overview of risk mapping, critical section, and recommendations for maintaining the integrity of the flexible pipeline will be presented.

Keywords: Flexible pipe, subsea pipeline, risk, QRBI, integrity.

1 Introduction

As an oil and gas producing country, Indonesia has oil and gas fields located both onshore and offshore. According to Indonesian Ministry of Energy and Mineral Resources, almost 70 percent of Indonesia's oil and gas reserves are in tertiary basin and more than half are in the deep sea. Some of them are already in the operational phase and some are still in the development phase. One of the common infrastructures in the oil and gas transmission sectors is pipeline and to transport hydrocarbon fluids safely, the pipeline must be able to respond to the challenges especially in a subsea operation which are high risk, high cost, and high technology. To answer these challenges, flexible pipe is one type of export pipeline and riser that has been successfully developed since 1970s and has become one of the solutions in the offshore technology [1].

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During the operational phase, the flexible pipe might suffer degradation which can lead to the failure. The degradation commonly occurred due to the interaction between pipe material, containing fluid and the surrounding environment. There are many damage mechanisms that may occur in flexible pipes during their service life, such as damage of tensile armors due to fatigue, kinks due to corrosion and over bending. The above-mentioned defects are very common and can lead to the failure of flexible pipes. Therefore, huge operational costs must be spent to ensure the integrity of the flexible pipeline system. Risk-Based inspection (RBI) methodology can establish a cost-effective strategy for inspection and monitoring, while maintaining the expected level of safety [2].

The purpose of this study is to propose a methodology to assess the integrity of a flexible pipeline that currently operate in Indonesian Deep Sea. The integrity assessment of flexible pipeline will be developed by utilizing Muhlbauer's Index Method, and Quantitative Risk Based Inspection (QRBI) approach with several adjustments.

2 Flexible Pipe System

With the rapid development of pipeline engineering technology, flexible pipes have been widely used in the oil and gas industry, both onshore and offshore. They are considered to be an efficient solution in terms of technical as well as economic performance due to their easy and fast laying procedure, durability, and recoverability. Based on the type of material, flexible pipe is divided into two categories, namely metal based and composite based which are covered by applicable codes and standards such as API RP 15 and 17 series.

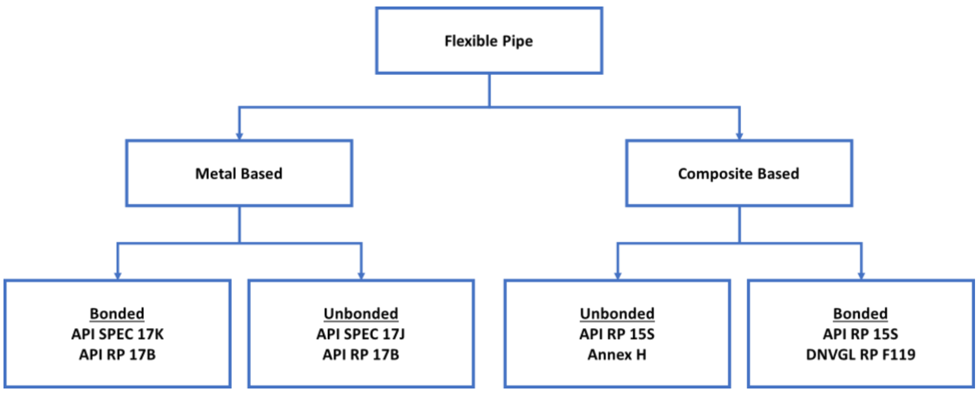

Fig. 1. Flexible Pipe Categorization [1].

Each flexible pipe categories have their own characteristics to fulfil the needs of operation condition, yet their main function of them is to convey the production fluid through a Flexible Pipe System (FPS). This system has many functions as gathering, exporting, and importing different kinds of fluids [3]. The constituted system of FPS may consist of one or more flexible pipes and its components, while the flexible pipe also can be defined as a system because it is constructed and installed from many components such as connectors, end-fittings, and the individual flexible pipe body. Figure 2 below shows the breakdown of a flexible pipe system.

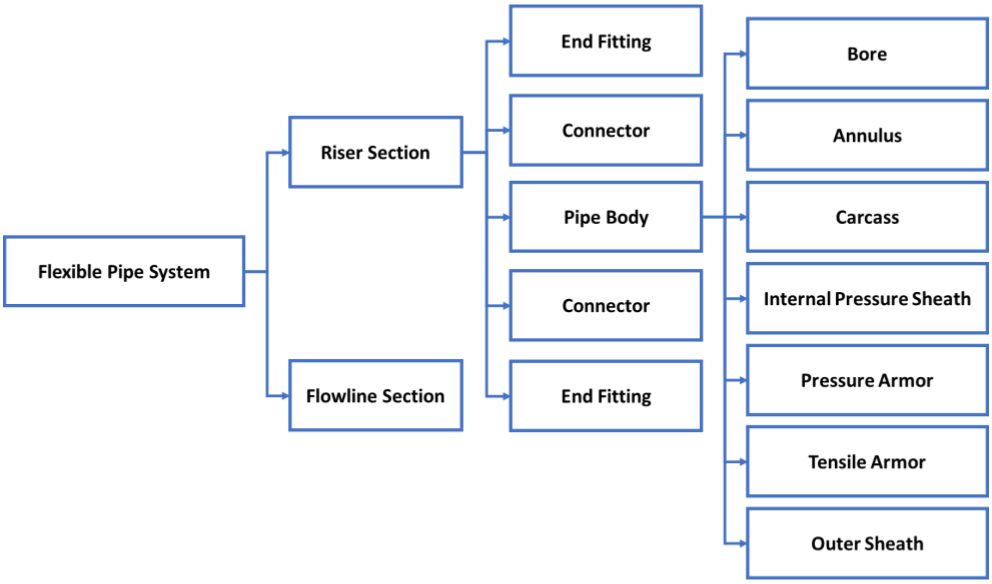

Fig. 2. Breakdown of Elements in Flexible Pipe System [3].

3 Pipeline Risk Assessment

The purpose of pipeline risk assessment is to identify the risk by generating relevant information about existing condition and potential damage mechanisms. Risk is defined as a measure of potential loss in terms of both the likelihood (or frequency of occurrence) of an event and the magnitude of the consequences from the event. By identifying the risk, it can help the operator to determine further actions to take decisions and establish strategies to maintain the integrity of the pipeline3. One of the methodologies of pipeline risk assessment that is commonly used in the oil and gas industry is Muhlbauer's Index Method, alongside the other such as ASME B31.8S, API RP 1160, BS PD 8010 and DNV GL RP F116.

The risk analysis of methodology of flexible pipe in general has been proposed by several papers in the past 20 years. Longo, et all (2010) has been proposed a strategy for risk analysis of flexible pipe system. The work has highlighted that the risk analysis is a key-issue for managing the integrity of flexible pipe and the risk analysis itself is divided to several phases such as qualitative analysis as the preliminary phase and quantitative analysis as the more advanced phase which requires a perform to figure out the probabilities and the consequence effects of the potential failure that have already studied and identified in preliminary phase [3]. Hameed, et al (2018) published an overview of risk-based inspection planning for flexible pipeline. The work is discussed about the optimization of risk-based inspection methodology for managing the integrity of flexible pipe. It is stated that if risk-based inspection is done correctly, then it can reduce the frequency of inspections while ensuring the risk does not increase [2].

Nowadays, the model type for determining the risk of pipeline is already developed. The risk model can be a qualitative model or quantitative model. The qualitative model uses inputs and outputs that are verbal or ordinal categories. A model logic defines output categories from combinations of input categories. The quantitative model is a model with input that is quantitative and output that is quantitative. The quantitative model uses the term of probability frequency. The example of the quantitative model (Quantitative Risk Based Inspection or QRBI) is API RBI 581 2016 and Muhlbauer's 2015. In general, the risk analysis of flexible pipe consists of these following steps:

1) Data Collection
2) Identification of Damage Mechanism
3) Segmentation
4) Risk Assessment
5) Acceptance Criteria

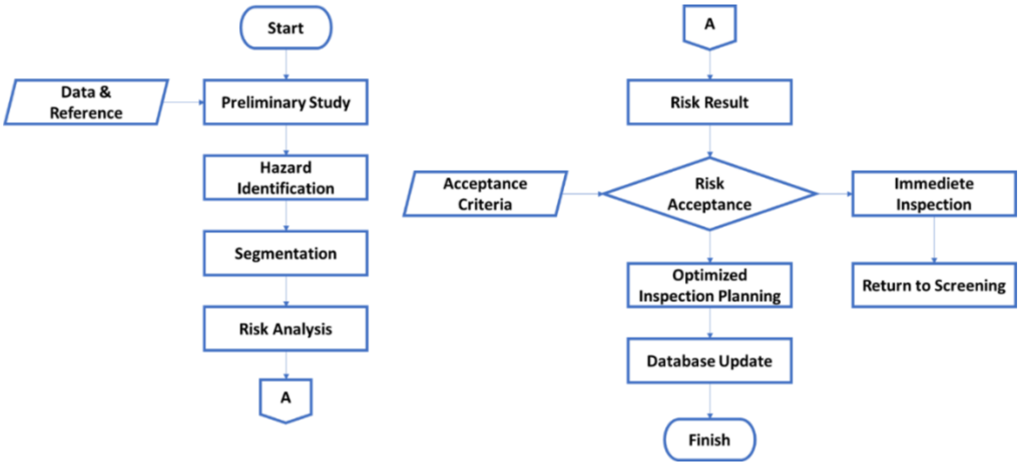

Fig. 3. General Methodology of Pipeline Risk Assessment

4 Data Input and Parameters

As mentioned in the introduction section above, Indonesia has oil and gas fields that located in deep sea, both those that are already operating or those that are currently in development phase. The characteristics of Indonesia's oil and gas fields which are located in the deep water are that they are located at a depth of more than 200 meters below sea level. Figure 4 below shows a map of the location of oil and gas fields which are categorized as fields located in the deep water of Indonesia, where a certain location will be taken as an example case for this study.

Fig. 4. Indonesia Deep Water Blocks with Water Depth > 200 m

Preliminary study is the first step to take in conducting a risk assessment pipeline. Data for preliminary study shall be collected in the form of design data, operation data, and environmental data. In addition, inspection history data and failure history will be very helpful to speed up the analysis process. The more complete and comprehensive data will also make the level of sensitivity in the work better so that the results obtained can reflect the actual level of the pipeline risk. The following example is going to present a risk assessment and integrity analysis of flexible subsea pipe that is currently in operation phase in Indonesia deep water oil and gas fields.

Table 1. Flexible Pipe Data

Variable	Value	Unit
Pipeline Length	0.468	Km
Outside Diameter	473.08	mm
Operating Pressure	1441	psi
Main Product	Gas	-

A good understanding and proper information regarding the flexible pipe damage mechanisms are required to assess the integrity of flexible pipe. The following information that may help the identification of flexible pipe damage mechanisms are [3]:
1) Design specification of flexible pipe including all calculation.
2) Knowledge about the service history of flexible pipe.
3) Determine the future expectations with respect to service of flexible pipe.
4) Information about the failure of flexible pipe.
5) Behavior of flexible pipe.
6) Estimate the likelihood of operation beyond the design specifications including some aspects as like accidental loads, temperature, accidental variations in internal environment, pressure, the composition of product, and dropped objects.

The damage mechanisms of flexible pipe may occur in specific area of flexible pipe structure. Figure 5 below shows an illustration of damage mechanism mapping that nay occur in flexible pipe structure.

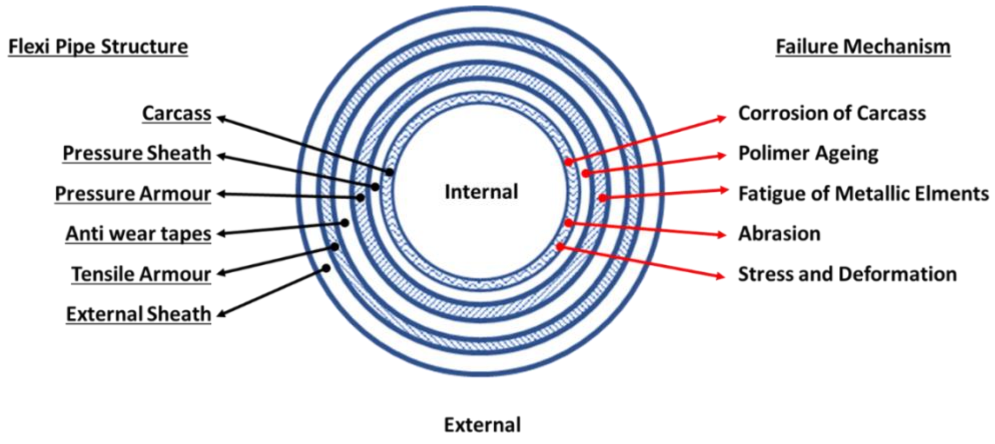

Fig. 5. Schematic of Flexible Pipe and its Damage Mechanisms

After the damage mechanism of flexible pipe has been listed, the next step is creating flexible pipe segmentation. The basis for creating segmentation is that the level of risk along the flexible pipe is not always similar which can be caused by differences in construction material designs and differences in environmental conditions. In this study, the determination of pipeline segmentation is dynamic based on environmental changes, where environmental changes will affect the risks that arise in the area or segment (dynamic segmentation). Determination of pipeline segmentation is determined by considering environmental conditions. Pipeline segmentation based on environmental conditions is to divide the length of the pipeline based on changes in environmental characteristics along the pipeline. Following are the flexible pipe segments used for this study:
1) Riser
2) Flexible Pipe (Flowline Section)
3) Touch Down Point (TDP) .

The following figures (Figure 6 and Figure 7) shows the environmental condition (topography) and the comparison of water depth at several Indonesia deep water fields.

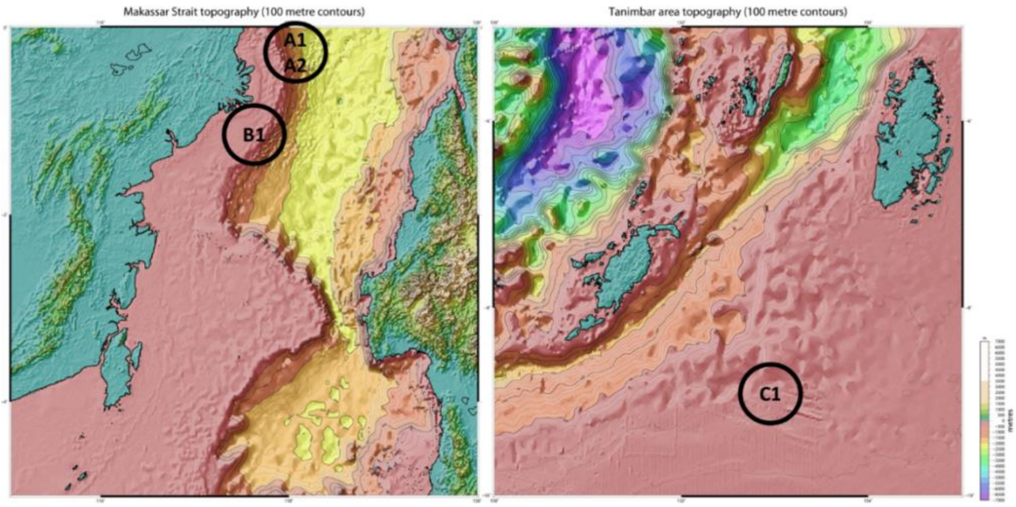

Fig. 6. Topography of Indonesia Deep Water Fields [4].

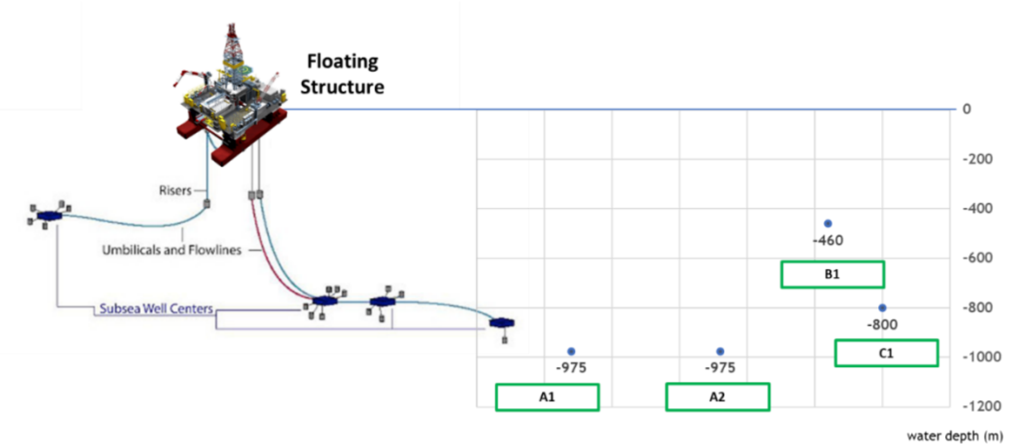

Fig. 7. Water Depth in Several Indonesia Deep Water Fields

5 Probability of Failure Assessment

After hazard identification and flexible pipe segmentation has been successfully carried out, the next step is to conduct a failure probability assessment. The characteristics of segments of the pipeline and the surrounding area are used to derive an actual estimate of the risk for each segment. Probability of Failure (PoF) is estimated as the frequency of failure along each segment over a year's time (or over some other relevant period). The PoF value is estimated as the failure frequency of various types of degradation mechanisms operating in the piping system. All component failures must be included in the PoF assessment. According to Muhlbauer's 2015 methodology [5], each damage mechanism must have three aspects that are measured independently as follows:

1) Exposure (attack) – The type and aggressiveness of the environmental or process exposure that can trigger failure. Exposure has units of events per mile-year or mils per year metal loss.

2) Mitigation (defense or protection) – The type and effectiveness of any mitigation measures designed to prevent or reduce exposure.

3) Resistance (resistance of the material) – the ability of a material (eg pipelines) to retain its mechanical properties against exposure in the event of a mitigation failure.

The idea of those three aspects can be explained in a swish cheese analogy. The exposure aspect is analogized as the potential hazard while the mitigation and resistance aspect are analogized as the swish cheese slices. The more cheese slices are added and/or the fewer holes on the cheese will reduce the event probability. Figure 8 below shows the illustration of swish cheese analogy.

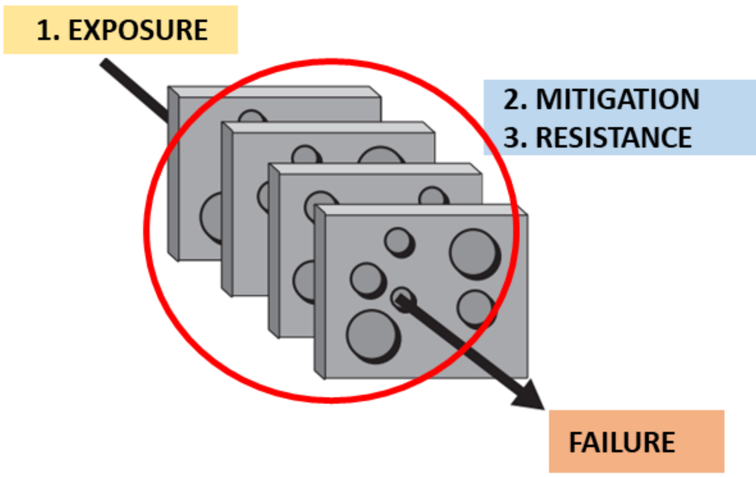

Fig. 8. Swish Cheese Analogy [5].

Several assumptions for PoF calculation are used to get the value of final PoF. The QRBI approach is taken by calculating the three aspects of exposure, mitigation, and resistance. Table 2 below summarized the PoF value for each flexible pipe segment.

Table 2. Summary of PoF Value of Each Flexible Pipe Segment

Segment	Damage Mechanism	PoF Value* (failure per year)
Riser	Above Water Level Riser Internal Corrosion	1.21×10^{-3}
	Above Water Level Riser External Corrosion (Marine Atmospheric)	1.54×10^{-3}

	Below Water Level Riser Internal Corrosion	1.21×10^{-3}
	Below Water Level Riser External Corrosion	2.63×10^{-3}
Flow Line	Carcass Internal Corrosion	3.28×10^{-3}
	Sand Erosion	7.19×10^{-4}
Touch Down Point	Deep Sea Debris Impact	2.66×10^{-5}
	Sand Erosion	2.26×10^{-3}
***Assumption based value**		

6 Consequence of Failure Assessment

The impact of pipeline failure could have on the public safety, the environment, the asset, the economy consequences, and the company reputation. Those consequences will be selected by decision making criteria and also considering the real operation condition of the flexible pipe. In estimating the consequences, input variables that is needed must represent the important characteristics of the pipeline segmentation such as the product being transported, the location of the pipeline segment, and the potential path of product release between the pipeline segment and the receptor (personnel, public, environment, public property, etc.). Table 3 below shows the example of consequence level for safety, environment, economy, and company reputation by considering the product that is being transported.

Table 3. Example of Consequence of Failure Level for Each Segment

Segmentations	Safety	Environment	Economy	Reputation
Riser	D	B	D	C
Flowline Section	B	B	D	C
Touch Down Point	B	B	D	C

Above table shows the example of CoF level for each segment. The consequence level scale is from A to E, where E is the highest. The basis of the safety consequence is manning levels which is ranked from human injury level (from no injuries to fatality). The toxicity level of hydrocarbon can be a factor to consider for determining the safety consequence level. Riser has the highest level of safety consequence compared to flowline section because the riser segment is close to human activity especially the above water level riser section. The consequence level for environment for each segment is considered in the level scale of B. The basis of level consideration is the transported fluid which is gas as it is not in the term of impactful to environment compared to other hydrocarbon such as oil and condensate. For economy consequences, the consequence level is in D scale. The consideration of this scale level because the term of economy is considering the loss of production, the down time, and asset repair or even asset replacement. The last is reputation impact which has the consequence level scale of

C. The considerations for this consequence category are the environment sensitivity level, how much the product is released, and the media coverage (local level or international level).

7 Risk Interpretation in Risk Matrix

The risk for each segment is estimated as the product of the PoF and the expected CoF. The total risk will be obtained by combining the value of PoF and CoF. The tolerable level of risk accepted by operators should be within a balance among the expenses for risk decreasing with the consequences of a failure incident. Each activity also must be carried out on a tolerable risk criterion, otherwise risk control must be carried out through a mitigation action plan to reduce the risk to an acceptable level. Any activity risk that falls outside the criteria must have a justification for continuing operations and obtain approval from management. To help categorize the level of risk, the risk value obtained in this study are displayed in an example of generic 5x5 risk matrix.

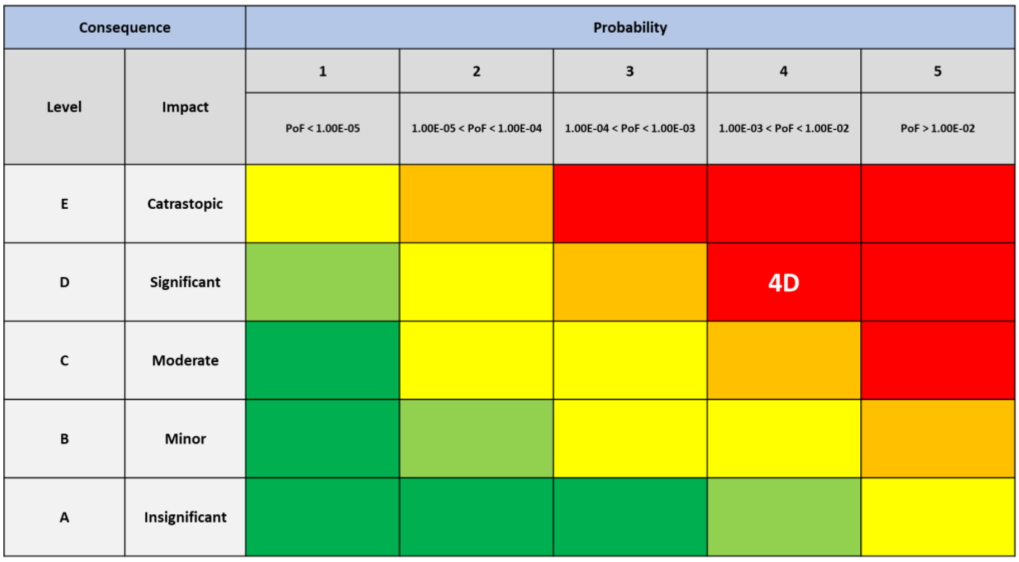

Fig. 9. Risk Result in Risk Matrix

The obtained risk of flexible pipeline segment requires a proper risk management strategy by considering the highest value of damage mechanism as the major concern to be prioritized. According to the QRBI approach, a set of programs that consist of inspection, maintenance and repair action must be developed because it is a cost-efficient decision framework for providing necessary maintenance activities by considering the final risk value of every flexible pipe segment.

Table 4. Summary of Segmentation Final Risk

Segmentations	Total PoF Value (Failure per year)	Final CoF Category	Risk Level
Riser	6.59×10^{-3}	D	4D
Flowline Section	3.99×10^{-3}	D	4D
Touch Down Point	2.26×10^{-3}	D	4D

Aside of risk matrix, one of the methods that can be used to understand the damage mechanism scenarios and its consequences is bow-tie analysis. The use of bow-tie analysis can help the risk interpretation becomes easier, since it shows a visualized overview of a hazard, provides all the critical information of risk such as threats, critical events, barriers, and consequences [6]. Figures 10 and 11 below are giving example of bow-tie application to understand the damage mechanism of a flexible pipe.

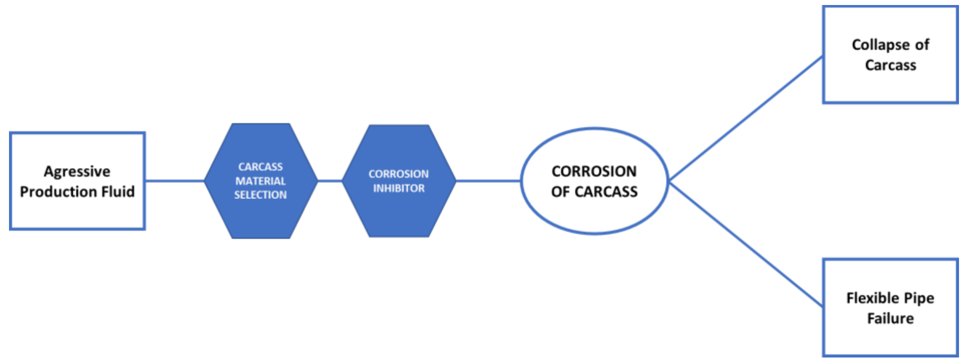

Fig. 10. Bow Tie Diagram of Carcass Corrosion

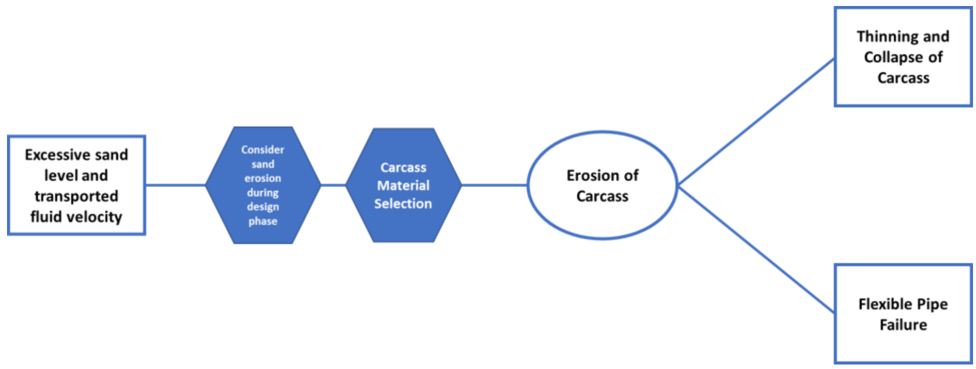

Fig. 11. Bow Tie Diagram of Carcass Errosion

8 Conclusion

The QRBI approach has become the most preferred method in assessing risk of oil and gas equipment especially in pipeline risk assessment. The QRBI approach gives the answer to simple index methods limitations; ineffective analysis of complex risk factor interactions and poor capability to identify risk drivers. By utilizing QRBI approach, the inspection, maintenance, and repair program (IMR program) will be developed and become a worth deal of strategy to maintain the integrity of flexible pipe system.

The QRBI approach for assessing flexible pipe system would never be utilized optimally as it requires more sensitivity on every step of pipeline QRBI process. For example, in segmentation step, there is factor to considers such as operation condition both for internal and external side of flexible pipe. In damage or hazard identification step, damage mechanism analysis on specific flexible pipe structures as it constructed from different materials. The load conditions and flexible pipe configuration also has to consider as it has to deal with the phenomenon of internal flow induced pulsation (FLIP) and external vortex induced vibration (VIV). In order to obtain a good understanding in the development of flexible pipe QRBI approach, specific cases are required to ensure this development to maintain the integrity of flexible pipe especially in Indonesia deep water oil and gas fields could be more reliable.

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