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Analysis of Inspection Scheduling on Free Spanning Subsea Pipeline Using Risk Based Inspection (RBI) Method

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ABSTRACT

The subsea pipeline system of PT. X located at north of West Java transports natural gas with 19 kilometers long and 16 inches standard pipe size. The rough seabed causes free span problem. The system will be threatened by a structural failure of fatigue due to Vortex Induced Vibration (VIV) and local buckling as the effects of free span. In this Final Project, a total of 136 free spans on subsea pipeline system due to the uneven seabed are analyzed. The screening will be done for spans with length and diameter ratio more than 30 to figure out the free span which pass the screening and know the risk level of the subsea pipeline due to free span. The result for fatigue screening due to VIV, spans with a length more than 25 meters did not pass the screening. Local buckling occurred at the longest free span with a length of 62 meters. The level of risk to structural failure caused fatigue due to VIV has the highest level in terms of business and the environment, namely in the medium category. The level of risk to local buckling failures for safety, environmental, and business terms was in low category.

Keywords: *free span, Risk-Based Inspection, subsea pipeline, VIV, local buckling*

1. INTRODUCTION

Pipelines are the most effective means of transport in delivering oil, gas, water, and chemical chemicals [1]. The use of subsea pipelines can reduce transportation costs up to one fifth, and pipelines can deliver hydrocarbons in real time [2]. The Pipeline is also very environmentally friendly transportation, but it is very harmful to the environment in case of failure [1].

At the time of operation of the subsea pipe had problems resulting from the contour of rough seabed as it is on land, this causes the pipe to experience a free span. The free span of the subsea pipelines may pose a risk of buckling and fatigue caused by vibrations. Local buckling can occur when the subsea pipes experience combined pressure, longitudinal force, and bending [3]. While fatigue in the subsea pipeline structure can occur when the frequency of the vortex flow formed at the around of the pipe is close to the natural frequency of the pipeline itself, this vibration can result in fatigue damage that cannot be left on the structure [4].

Possible failures occur with the pipeline with free span. So, it is necessary to determine the interval of inspection time to prevent the pipeline from failure. Responding to this, Risk based inspection (RBI) are developed. Risk based inspection is a systematic approach of inspection management method for equipment or work units on a system, based on the level of its risk [5].

This analysis will be conducted on the subsea pipe network owned by PT. X is located in the North Sea of West Java. The subsea pipeline transports natural gas from platform A to platform B with a 19 km long and 16" diameter pipe. In the subsea pipe PT. X There are 136 free span along the pipe with the longest free span is 62 m.

Therefore, it is necessary to do a risk analysis on the PT. X Subsea Pipeline to ensure that the bottom pipeline is reliable enough to provide its function with the free span problem.

2. METHODS

2.1 Free Span Analysis

A free span occurs when the subsea pipeline loses contact with the seabed. Free span can occur due to uneven seabed surfaces, changes in the sea bottom contour, and artificial support [6]. Free spanning pipeline must be able to resist excessive yield, fatigue, and buckling [7]. In fact, subsea pipes do not experience only single span but also there are multiple span. For the overview of single span and multiple span can be seen in Figure 1.

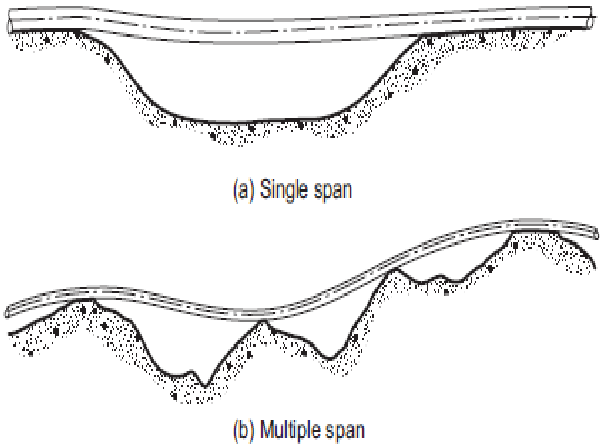

Figure 1. Illustration of Single Span and Multiple Span[7].

In this analysis, the screening will be conducted to ensure that the span in a safe condition or not. The analysis is performed only on spans with length and diameter ratio more than 30 ratio.

In the span analysis, the result used for further analysis is the natural frequency of pipeline. Equation used in the calculation of Natural frequency pipe as in DNV RP F105 as follows:

$$f_1 \approx C_1\sqrt{1+CSF}\sqrt{\frac{E_{st} I_{st}}{M_e L_{eff}^4}\left(1+\frac{S_{eff}}{P_{cr}}+C_3\left(\frac{\delta}{D_t}\right)^2\right)} \qquad (1)$$

Where, C1 and C3 are the boundary condition coefficients for pinned-pinned 1.57 and 0.8, the CSF is Concrete stiffness factor Est is the Young's modulus of pipe, Me effective mass of pipe, Seff is an effective axial force, PCR is a critical buckling load and D is static deflection.

2.2 Vortex Induced Vibration (VIV)

VIV occurs when the seawater flow flows through the subsea pipelines, vortices appear behind the pipeline. Vortices are occurring Caused by turbulence and flow instability behind the pipeline [8]. The reverse current that occurs due to vortex shedding will cause a cyclic load on the pipe that causes vibration [3]. The illustration of VIV can be seen in Figure 2 as follows.

VIV is acceptable as long as it does not exceed allowable fatigue damage [3]. To ensure the subsea pipe can operate more than 50 years in the face of the phenomenon VIV then it is necessary to do fatigue screening due to VIV after that in DNV RP F105. The equation of the limit state to ensure the pipeline can last more than 50 years of operation as follows:

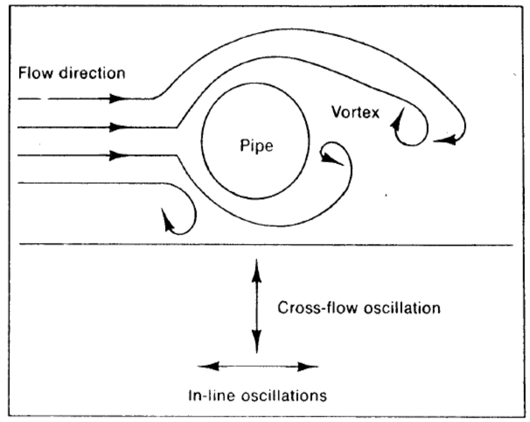

Figure 2. Vortex induced vibration [8].

Fatigue screening Equation In-line condition

$$\frac{f_{n,IL}}{\gamma_{IL}} > \frac{U_{c,100tahun}}{V^{IL}_{R,onset}\cdot D}\cdot\left(1-\frac{\frac{L}{D}}{250}\right)\cdot\frac{1}{\alpha} \qquad (2)$$

Fatigue screening Equation cross-flow condition

$$\frac{f_{n,CF}}{\gamma_{CF}} > \frac{U_{c,100tahun}+U_{w,1tahun}}{V^{CF}_{R,onset}\cdot D} \qquad (3)$$

2.3 Local Buckling

Local buckling checks for subsea pipelines that have a free span must conform to combined loading and load controlled [6]. In DNV OS F101 local buckling failure criteria for condition combined loading and load controlled will be displayed in the following equation:

$$\left\{\gamma_m\cdot\gamma_{SC}\cdot\frac{|M_{sd}|}{\alpha_c\cdot M_p(t_2)}+\left\{\frac{\gamma_m\cdot\gamma_{sc}\cdot S_{sd}(p_i)}{\alpha_c\cdot S_p(t_2)}\right\}^2\right\}^2 + \left(\alpha_p\cdot\frac{P_i-P_e}{\alpha_c\cdot P_b(t_2)}\right)^2 \leq 1 \qquad (4)$$

For: $15 \leq D/t \leq 45$, $P_i > P_e$, $|S_{sd}| / S_p < 0.4$

$$\left\{\gamma_m\cdot\gamma_{SC}\cdot\frac{|M_{sd}|}{\alpha_c\cdot M_p(t_2)}+\left\{\frac{\gamma_m\cdot\gamma_{sc}\cdot S_{sd}}{\alpha_c\cdot S_p(t_2)}\right\}^2\right\}^2 + \left(\alpha_p\cdot\frac{P_e-P_{min}}{P_c(t_2)}\right)^2 \leq 1 \qquad (5)$$

For: $15 \leq D/t \leq 45$, $P_i < P_e$, $|S_{sd}| / S_p < 0.4$

Where $\gamma_{m,}$ γ_{sc} is a material endurance factor and material durability security factor, and its value 1.15 and 1,138 in accordance with [9] Msd is bending moment, S_{SD} is an effective axial force, and Pi and Pe are internal and external pressures. The bending moment can be calculated using the equation below.

$$M_{sd} = \sqrt{(M_F \cdot \gamma_F \cdot \gamma_C)^2 + (M_{E(CF)} \cdot \gamma_E)^2 + (M_{E(IL)} \cdot \gamma_E)^2} \tag{6}$$

Where M_F is bending moment due to functional load, M_E is bending moment due to environmental load.

2.4 Reliability Analysis

For a system which its variables have random values, Monte Carlo simulation can be used in analyzing its reliability. This simulation can be easily done with the help of a computer, where there is an RNG (Random Number Generator) which is then the number issued by the RNG is used as the probability of a random number or parameter on a system. But the distribution of probability from random changer contained in a system must be known first or can be assumed [10]. A random changer that has been known to its opportunity distribution is inputed into the performance function of a system F_k (x), and the price of F_k (x) then calculated. When the performance function has a value less than equal to zero then a review system is considered to be failed ($F_k(x) \leq 0$). When the simulation is done then the number of samples obtained will be as much as N times. Whereas when the $F_k(x) \leq 0$ Then many samples of failures that occurred are recorded n times. Thus the chances of failure of a system can be known that the incidence rate fails with the number of samples or replication [10] as in the equation below.

$$P_g = \frac{n}{N} \tag{7}$$

Where P_g is the chance of failure, N is the number of failed events, and N is the number of samples. For failure mode used in the reliability analysis of the following equations.

$$F_k(x) = \frac{f_{n,IL}}{\gamma_{IL}} - \frac{U_{c,100tahun}}{V^{IL}_{R,onset} \cdot D} \cdot \left(1 - \frac{\frac{L}{D}}{250}\right) \cdot \frac{1}{\alpha} \leq 0 \tag{8}$$

$$F_k(x) = \frac{f_{n,CF}}{\gamma_{CF}} - \frac{U_{c,100tahun} + U_{w,1tahun}}{V^{CF}_{R,onset} \cdot D} \leq 0 \tag{9}$$

$$F_k(x) = 1 - \left\{ \gamma_m \cdot \gamma_{SC} \cdot \frac{|M_{sd}|}{\alpha_c \cdot M_p \cdot (t)} + \left\{ \frac{\gamma_m \cdot \gamma_{sc} \cdot S_{sd}(p_i)}{\alpha_c \cdot S_p \cdot (t)} \right\}^2 \right\} + \left(\alpha_p \cdot \frac{P_i - P_e}{\alpha_c \cdot P_b \cdot (t)} \right)^2 \leq 0 \tag{10}$$

2.5 Risk Matrix

Risk matrix is a matrix that gives an overview of the risks that occur. To get a detailed risk level, a 5x5 risk matrix is recommended [11]. The risk itself is found from the results of the multiplication of failure Odds (POF) with the consequences of failure (COF). For risk matrix is taken from DNV codes RP F116 and will be shown in Figure 3.

Usually, for a low risk level is still acceptable, and it is necessary to visually inspect to maintain a fixed risk value at this level. Medium risk is also acceptable, but need to be in the action such as, nondestructive testing, functional test and others to keep the risk of not increasing. Then for high risk, the action should be taken to reduce the chances of failure or the consequences, thereby lowering the level of risk [11].

Increasing consequences ↑ / Severity	Increasing probability: 1 Failure is not expected $< 10^{-5}$	2 Never heard of in the industry $10^{-5} - 10^{-4}$	3 An accident has occurred in the industry $10^{-4} - 10^{-3}$	4 Has been experienced by most operators $10^{-3} - 10^{-2}$	5 Occurs several times per year $10^{-2} - 10^{-1}$
E	3	1	N/A	N/A	N/A
D	5	3	1	N/A	N/A
C	8	5	3	1	N/A
B	8	8	5	3	1
A	8	8	8	5	3

Figure 3 . Risk Matrik along with maximum inspection time interval.

The time Interval in the risk matrix in Figure 3 should be multiplied by the analysis belief factor, and the material creation factor. For analysis of this belief factor analysis and factor material making is worth 1.

3. RESULTS AND DISCUSSION

3.1 Free Analysis

Free Span analysis was used to determine the natural frequency of pipes in each of the free expansions that do not qualify for the L/D ratio screening. A span that has a ratio of L/D to more than 30 was considered causing a failure, fatigue due to VIV and local buckling. PT. X Subsea Pipeline Data are displayed in table 1 as follows:

Tabel 1. Pipe Data

Pipe Data	Units	Symbol	Value
Material Grade	API-5L-X60		
Pipe Diameter	m	Ds	0.406
Thickness	m	t *nom*	0.014
Corrosion allowance	m	t_{intcor}	0.003
Nominal thickness	m	t_2	0.011
Steel Density	Kg/m^3	ρ *pipa*	7850
Young Modulus	N/m^2	E *pipa*	2.07E+11
Poison ratio		*v*	0.300
SMYS	Pa	SMYS	4.14E+08
SMTS	Pa	SMTS	4.86E+08
Coefficient of thermal expansion	$/^0C$	a_e	1.10E-05
Pipe Diameter	m	Ds	0.406
Wallthickness	m	t *nom*	0.014
Corrosion allowance	m	t_{intcor}	0.003
Norm Wallthickness	m	t_2	0.011

Tabel 2. Pipeline Coating Data

Coating data	Units	Symbol	Value
Corrosion thickness	m	t_{cor}	3.97E-03
Corrosion coating density	Kg/m^3	ρ cor	1280
Thickness concrete coating	m	t concrete	0.051
Concrete density	Kg/m^3	ρ concrete	3043.508
Young modulus concrete	Pa	E concrete	4.10E+10
Surface roughness	m	K	0.003

Tabel 3. Pipeline Operation Data

Operation data	Units	Symbol	Value
Fluid density	Kg/m^3	ρ fluida	29.3
Flow Rate	MMSCFD	Q	35.82
Operating Pressure	N/m^2	P_i	1.38E+06
Operating Temperature	^0F	T_i	90
Suhu air laut	^0C	T	27

($F_k(x) \le 0$) For the calculation of natural frequency of pipes on a free span that does not pass screening L/D can be seen on the chart in Figure 4.

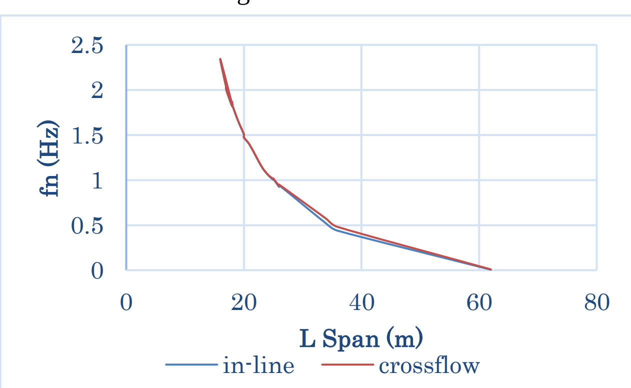

Figure 4. Comparison Between Natural Frequency of Pipes with Length of Span

As shown on the figure 4, the longer the span occurs then the natural frequency of the pipe will decrease. This can be harmful because smaller frequency of the pipeline will often occur vibrations.

3.2 Screening for Fatigue Due to VIV

Screening was done to the spans with length per diameter ratio more than 30 can last more than 50 years with VIV. Results were found by comparing the maximum natural frequency possible with the natural frequency of pipes. For fatigue screening results due to VIV can be seen in table 4 below.

Table 4. Results of model validation in-line condition

KP	F_{NIL}/γ_{IL}	RIGHT SIDE	*SCREENING*
0.78	1.19	0.32	success
1.55	1.06	0.34	success
2.163	0.95	0.38	success
2.343	0.54	0.37	success
2.381	0.59	0.38	success
2.552	1.18	0.40	success
2.737	1.21	0.43	success
2.882	1.33	0.43	success
3.07	0.64	0.41	success
3.155	0.93	0.42	success
KP	F_{nIL}/γ_{IL}	**Right side**	***Screening***
3.194	0.86	0.44	success
3.406	0.70	0.44	success
11.974	1.19	0.50	success
12.485	1.35	0.53	success
14.385	1.34	0.57	success
16.365	0.55	0.53	success
16.392	0.31	0.48	fail
16.431	1.54	0.57	success
16.811	1.31	0.52	success
17.665	0.60	0.53	success
17.913	0.01	0.34	fail
18.922	0.30	0.51	fail

Table 5. Results of model validation cross-flow condition

KP	F_{NCF}/G_{CF}	RIGHTSIDE`	*SCREENING*
0.78	1.19	0.42	success
1.55	1.06	0.46	success
2.163	0.95	0.50	success
2.343	0.54	0.52	success
2.381	0.60	0.51	success
2.552	1.18	0.55	success
2.737	1.21	0.53	success
2.882	1.33	0.58	success
3.07	0.64	0.59	success
3.155	0.93	0.61	success
3.406	0.70	0.63	success
11.974	1.19	0.66	success
12.485	1.35	0.67	success
14.385	1.34	0.75	success
16.365	0.55	0.70	success
16.392	0.34	0.69	fail
16.431	1.54	0.69	fail
16.811	1.31	0.74	success
17.665	0.60	0.70	success
17.913	0.01	0.69	fail
18.922	0.32	0.74	fail

The right side of the table above is an equation to the natural frequency of the environment in the equation above. From the screening results on the subsea pipe PT. X cannot last more than 50 years when experiencing VIV for a free span length of 25 meters and above.

3.3 Screening for Local Buckling

Spans in pipe with the length per diameter ratio more than 30 were also screened to know if there were local buckling in the pipeline. Local buckling needs to be checked because when local buckling occurs then the risk of collapse is getting bigger than without the local buckling.

Table 6. Results of model validation local buckling

KP	D (M)	L (M)	RATIO *LOCAL BUCKLING*	SCREENING *LOCAL BUCKLING*
0.78	29.3	18	0.01	success
1.55	25	19	0.04	success
2.163	21.8	20	0.03	success
2.343	20.9	26	0.06	success
2.381	20.7	25	0.05	success
2.552	19.8	18	0.02	success
KP	**d (m)**		**Ratio *Local buckling***	
2.737	19.2	18	0.02	success
2.882	18.5	17	0.02	success
3.07	18	24	0.04	success
3.155	17.5	20	0.02	success
3.194	17.3	21	0.03	success
3.406	16.5	23	0.03	success
11.974	19.2	18	0.01	success
12.485	18.3	17	0.01	success
14.385	16.1	17	0.01	success
16.365	16.7	26	0.04	success
16.392	17	34	0.15	success
16.431	17	16	0.01	success
16.811	17.3	17	0.01	success
17.665	16.8	25	0.04	success
17.913	17	62	14.69	fail
18.922	15.3	36	0.22	success

For the failure due to local buckling, only occurred at the longest span, with a length of 62 meters. This was due to bending moment inflicted on a functional weight.

3.4 Realibility Analysis

Reliability analysis was performed using the Monte Carlo method. This was done to know the value of PoF (probability of failure) of the subsea pipeline network PT. X in the face of the phenomenon VIV and local buckling. The failure modes used in the simulation was the formula of screening for fatigue due to the VIV phenomenon for both in-line and cross-flow conditions. For ULS mode failures used was a formulation for local buckling checking as in DNV OS F101. The main element required in Monte Carlo was a random number generator (RNG). The issued random number was assumed to be the PDF (Probability density function) of a random variables distribution.

The initial step in performing the reliability analysis using the Monte Carlo method was by specifying a random variable and specifying its distribution. Random variables in this reliability analysis were the length of the free span, the gap height, the velocity of the current particle due to tidal and the wave at the elevation of pipe, and depth.

The distribution determination was done with the help of EasyFit software. Easyfit assisted the process of determining distribution of data with goodness of fit test using 3 methods: Kolmogorov-Smirnov, Anderson Darling, and Chi-squared. It performed goodness of fit test up to 61 distribution types. The result of the test for each variables displayed on table 7 below.

Table 7. Random Variabels Distribution

Variabel acak	Distribusi	Mean	C.O.V
Length	LogLogistic	11.413	0.577
Gap Height	Burr	0.214	0.615
Depth	Burr	18.991	0.172
Uc100years	LogLogistic	0.405	0.018
Uw1year	Gen. Extreme	0.294	0.414
Uw100years	Dagum	0.900	0.129

After the distribution type of each random variable were known. The PDF Value that obtained from RNG was converted to the random variables value with the PDF from the EasyFit software. Reliability analysis performed simulations from 1000 to 100000 experiments. This is done in order to know the exact number of reliability that changes in reliability value do not change significantly. For reliability analysis results using the Monte Carlo method are be displayed in table 8 as shown below.

Table 8. Result of Reliability Analysis

VIV		
Simulation	Keandalan	Pof
100000	0.99277	0.00721

Table 9. Result of Reliability Analysis

Local buckling		
Simulation	Keandalan	Pof
100000	0.99827	0.00171

From the results of the reliability analysis can be seen that the subsea pipe PT. X was quite reliable in facing the problem of free span. Where the value of PoF for the phenomenon VIV reached 0.0072, while for local buckling pipe PT. X was more reliable in this issue with a PoF value of 0.0017.

3.5 Risk Matrix

a. Safety

The subsea pipe of PT. X is located in the Java Sea, it was assumed that in case of failure it will not cause

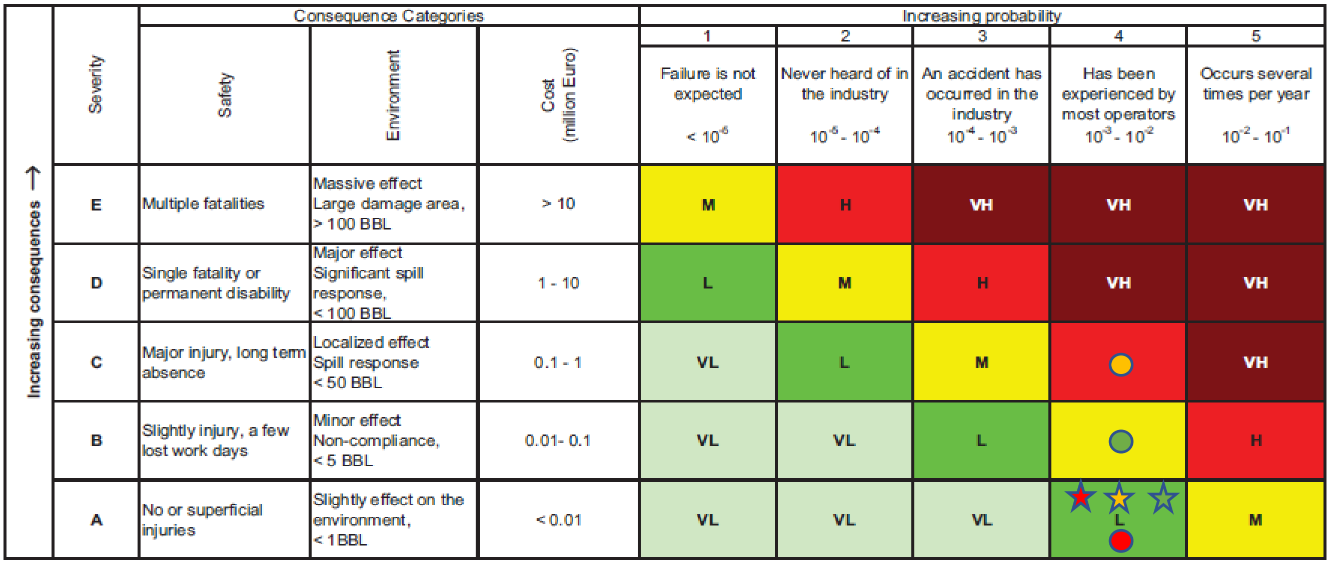

Figure 5. Risk Matrix Subsea pipeline PT. X

casualties. The pipeline was on the seabed, so there were no human activities around and just some ship that passed. Unlike the failure of the subsea pipeline to occur in the riser that could cause casualties. Referring to DNV RP F116 (2015) for safety consequences where there are no victims, the consequences were included in category A

b. Environmental

Subsea Pipelines PT.X transports natural gas from Platform A to Platform B. Local buckling only lead to deformation, so there won't be gas leaking. Thus, it was assumed that the consequences for the environment were categorized in category A. But the failure due to VIV and fatigue can cause gas leaking. According to Surapto (2007) in the final assignment [12] for the West Java region Natural Gas contains a medium CO2 and a low content of H2S. This could be concluded if there is leakage will contaminate the environment with CO2 and H2S can endanger the life of marine biota [13]. But the H2S content in natural gas in West Java is low. Therefore, for environmental consequences due to VIV phenomenon can be categorized B.

c. Asset

The failure of the subsea pipeline may cause the production process to stop and leakage. This could lead to high loss. Based on the gas price today (29 April 2020) for 1 MMBTU is at a rate of 6 USD. The known flow rate of pipeline network PT. X is about 36,823 MMBTU. So the estimated loss calculation will be shown in the table as follows.

Table 10. Total gas loss

Gas in pipe		***Flow rate***		**Gas total**
M^3	MMBTU	MMSCFD	MMBTU	MMBTU
2198.13	77.62	35.28	36823	36900.62

Table 11. Total money loss

Gas Total	**Total kerugian**	
MMBTU	USD	Euro
36900.62	221404	205905

The scenario calculation of loss assumed 1 day downtime was equal as PT. X failed to sell natural gas as much as 36823 MMBTU. Besides, the loss of natural gas due to leak around 77.62 MMBTU was up to 66,576 euros. Referring to DNV RP F116 consequence in terms of business belongs to category C. However the amount of loss will increase as the change or repair of the subsea pipeline continue.

After assuming about each consequence category based on DNV RP F116 (2015) and the value of PoF for VIV and local buckling then it could be known risk matrix for each failure occurring from various aspects of safety, environment, and business. The risk matrix for each failure and each of the consequences will be shown in the picture as follows.

The circle symbol on the picture is for the VIV and the star for local buckling. The colors to indicate the category of consequences are red for safety, green for the environment, and yellow for business.

In determining the interval of inspection time based on DNV RP F116 can be known by looking at Figure 3 above. For the inspection interval time and PoF category details and the consequences will be displayed in the table as follows.

The recommended inspection method for VIV is to use ROV. ROV itself has been used for a long time and even the data used above were taken by ROV. It is controlled by the operator from the survey vessel to be used for recording, taking pictures, checking the cathodic protection, certain objects around the pipeline, length of spans, and height of the gap between the pipe and seabed.

Table 12. Risk VIV failure

aspect	PoF VIV	Consequence VIV	Interval Inspection VIV
Safety	High (4)	A	5 years
Environment	High (4)	B	3 years
Bisnis	High (4)	C	1 years

Table 13. Risk local buckling failurue

Aspect	PoF *local buckling*	*The Consequence of Local buckling*	Interval Inspection *Local buckling*
Safety	High (4)	A	5 years
Environment	High (4)	A	5 years
Bisnis	High (4)	A	5 years

The results of a ROV survey can be used for subsequent analysis to monitor the risk of free span. The recommended inspection method for local buckling use in-line inspection is intelligent pigging tools. Its result can show if there is a dent or deformation on the subsea pipeline due to local buckling, and also provide information about the thickness of the pipe wall. For local buckling, it is better to follow RBI results for pipes with corrosion because the risk showed still low.

3.6 Mitigation

Span length evaluation was done for the span that passed neither structure fatigue screening due to VIV both in-line and cross-flow conditions nor the ULS screening (local buckling). It was done by finding the maximum span length for each Kilometer Point that does not pass the screening. The maximum span length calculation results are displayed in the table as follows.

Table 14. Calculation of Critical Length free span

KP	gap (m)	L (m)	$f_{n,in-line}$	$f_{n,cross-flow}$	$L_{cr,in-line}$	$L_{cr,cross-flow}$
16.365	0.6	26	1.64	0.89	14.23	20.49
16.392	0.5	34	1.61	0.87	14.35	20.85
17.665	0.55	25	1.63	0.88	14.28	20.63
17.913	0.6	62	1.62	0.88	14.32	20.74
18.922	0.5	36	1.73	0.94	13.86	19.44

The result showed the maximum length of the span for an in-line condition was shorter than the cross-flow condition. Therefore, span length evaluation was done with maximum length span in-line condition as the reference. It prevented the evaluated pipe to fail for inline and cross-flow conditions. To change the initial span length to be less than the maximum length of the span on the in-line condition need to be added support. In this analysis, artificial support was made by dividing the same average length of the initial span into sections to have a long value span of less than LCR in-line. Table 15 shows the amount of supports needed and the result of length per diameter ratio.

Table 15. Number of support added

KP	gap (m)	$L_{cr,in-line}$	n support	L_{now}	L/D
16.365	0.6	14.23	1	13.00	25.20
16.392	0.5	14.35	2	11.33	21.97
17.665	0.55	14.28	1	12.50	24.23
17.913	0.6	14.32	4	12.40	24.03
18.922	0.5	13.86	2	12.00	23.26

With the addition of supports for subsea pipes that did not pass the fatigue screening due to VIV or local buckling phenomenon, the PT. X Subsea Pipeline had an increase in reliability than before evaluating the length of the span. The reliability of the subsea pipeline PT. X after evaluation length of span is shown in Table 16 and 17.

Table 16. Results of reliability Analysis after the addition of support

VIV		
Numbers of Simulation	Reliability	Pof
100000	0.99807	0.00191

Table 17. Results of reliability Analysis after the addition of support

Local Buckling		
Numbers of Simulation	Reliability	PoF
100000	0.99986	0.00012

4. CONCLUSIONS

The results of the risk analysis of the free spanning subsea pipeline from PT. X using risk based inspection method could be drawn to conclusions as:

- The free span of the subsea pipeline of PT. X did not pass the fatigue screening of VIV for a free span with a length of over 25 meters and the longest free span experienced local buckling failure.
- The reliability value of the free spanning subsea pipeline of PT. X due to VIV was 0.993 and 0.998 for the local buckling.
- The level of risk for the subsea pipeline of PT. X failure due to the VIV phenomenon categorized as medium risk and low category for local buckling.
- The mitigation that carried out was inspection using ROV with three years interval and in-line inspection method using intelligent pigging with five years interval time, or the same interval time with corrosion inspection.
- Mitigation that was suggested to be carried out is span length evaluation for the pipe that did not pass the screening. Artificial support that could be used is the sand pack because the spans have a gap height of less

than 1 meter. Span length evaluation was quite effective as it increased the reliability of the subsea pipe PT. X although not significant because many free spans have a ratio of L/D more than 30. To lower the risk could be done by evaluating all the free spans that have a length per diameter ratio of more than 30.

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