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Risk Based Inspection using API RP 580 and DNV RP F116 Towards Free Spanning Pipelines

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ABSTRACT

The free span that occurs in the subsea pipeline can cause fatigue due to vortex induced vibration and local buckling. From the risk of failure that may occur, a risk-based inspection scheduling required. The 14" Underwater pipe belongs to PT. The X located in the Madura Strait is used to transmit gas from the CPP to ORF with a length of 65 km which has 554 free spans. In scheduling inspections, the commonly used codes are API RP 580 and DNV RP F116. This journal will discuss the difference between these two codes. Reliability calculations use Monte Carlo simulation with VIV failure mode and local buckling failure mode. The consequences of failure are reviewed on safety, environmental and asset aspects. API RP 580, shows the environmental aspect and the safety aspect of both modes of failure has the next inspection in 6 years, while the asset aspect is 3 years. At DNV RP F116, scheduling inspection of safety aspect on both modes is 3 years and environmental aspects is a year later, while the asset aspect would be better to change the pipe

Keywords: *free span, RBI, risk, VIV, local buckling.*

1. INTRODUCTION

The undersea pipes play an important role in the offshore oil and gas development process. The underwater pipe is used as a transport pipeline for export, pipe-producing production from a platform to export pipes, production conveying pipes between platforms, subsea doing and satellite wells [1]. Like the underwater pipe of PT. X which is located in the Madura Strait. This 14 "Subsea pipe delivers gas from the central processing platform (CPP) to onshore receiving facilities (ORF). However, when the use of subsea pipes enters the deep sea, the unruled underwater topographical state is more widely encountered [2].

Uneven topographical conditions can cause the presence of subsea pipes that do not have a buffer, thus forming a free span [3]. The free span has a significant impact on the safety and integrity aspects of the subsea pipeline [4]. The free span of subsea pipes can cause underwater pipe failure, among others is fatigue due to VIV and local buckling occurrence. Therefore, it is necessary to do risk based inspection to control the free expanse that occurs in the subsea pipeline.

Scheduling inspections consist of two words, schedule and inspection. Schedule is an activity plan that is done with the distribution of detailed implementation time. While the inspection is a direct and detailed examination according to the prevailing regulations [5]. So, it can be said that the inspection scheduling is a time planning of direct and detailed test activities according to the prevailing regulations. There are some commonly used codes for scheduling risk based inspection, such as API RP 580 and DNV RP F116.

This journal will discuss the comparison of risk-based inspection scheduling using API codes RP 580 with DNV RP F116. In risk analysis, calculation of the probability of failure is reviewed against the two failure modes, namely fatigue due to VIV and also local buckling. Meanwhile, in the analysis of the consequences will be reviewed in three aspects, the safety aspect, environment, and also assets.

2. BASIC THEORY

2.1 Pipeline data

The pipe that is reviewed is a pipe owned by PT. X operating in Madura Strait. This pipe has a length of 65 km to connect the central processing platform (CPP) to the onshore receiving facilities (ORF). The fluid that is flowed by this pipe is gas.

Table 1. Pipeline Data

Process Data		
Parameter	Unit	Value
Design pressure	Mpa	9.3
Operating pressure	Mpa	4.9
Design temperature	^{o}C	75
Operating temperature	^{o}C	65
Content density	kg/m^3	29.3

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Pipeline Property		
Parameter	Unit	Value
Outer diameter	mm	355.6
Material		CS
Seam		SMLS
SMYS	Mpa (psi)	360
SMTS	Mpa (psi)	400
Steel density	kg/m^3	7850
Young Modulus	Mpa	207000
Expansion thermal coefficient	1/ ^{O}C	0.0000117
Poisson Ratio		0.3
Wall thickness	mm	14.3
Internal corrosion allowance	mm	3

Table 2. Coating data

Coating Properties		
Parameter	Unit	Value
Asphalt Enamel thickness	mm	6
Asphalt Enamel density	kg/m^3	1280
Cutback- Asphalt Enamel	mm	200
Concrete coating thickness	mm	50.8
Concrete coating density	kg/m^3	2242.59

Table 3. Environment Data

Current Data		
Parameter	Percent of Depth	
	100	0
1 year (m/s)	1.07	0.24
100 years (m/s)	1.37	0.5

Wave Data		
Parameter	Return Period	
	1 year	100 years
Hs (m)	2.78	4.92
Ts (s)	5.4	7.5
Hmax (m)	5.18	9.14
Tmax (s)	7.2	10

Depth and tides		
Parameter	Unit	Value
Pipelines depth	m	56.693
MSL	m	1.11
Storm Tide (Surge)	m	0.09
High Astronomical Tide	m	2.44
MSL + Surge + 1/2 HAT	m	62.42

Seawater properties		
Parameter	Unit	Value
Density	kg/m^3	1025
Seabed temperature	^{O}C	28.88
Kinematic viscosity	m^2/s	0.0000113

Soil parameter		
Parameter	Unit	Value
Soil type	Very soft clay	
Undrained Shear Strength	kPa	4
Submerged soil density	kN/m^3	15.69

2.2 Free span

Free span occurs when the pipe part loses buffer or loses interaction with the ground. When the fluid passes through the expanse of the subsea pipeline, a vortex is formed behind the pipe that can make the pipe oscillating. When the pipe resonates with the other frequency, the pipe will undergo a failure due to fatigue [6]. Besides, a free span can cause local buckling. Local buckling is the condition where the underwater pipe exceeds the boundary of the ultimate pipeline due to the burden of various conditions [7]. The natural frequency of underwater pipes can be seen in the following equation

$$f_n \approx C_1\sqrt{1+CSF}\sqrt{\frac{EI}{m_e L_{eff}^4}\left(1+\frac{S_{eff}}{P_{cr}}+C_3\left(\frac{\delta}{D}\right)^2\right)} \quad (1)$$

The values of ***C1*** and ***C3*** are boundary conditions. While Leff is an effective span length or long span that has a focus pinned-pinned.

2.3 Monte Carlo simulation

The basic principle of Monte Carlo simulation is to take some random samples and variables related to the system reviewed [8]. Thus, in the use of this Monte Carlo simulation it takes a random number generator (RNG) and a random variable to the corresponding failure mode on the system being reviewed. The failure mode used in this simulation is the fatigue failure mode due to VIV in both in-line and cross-flow directions as well as the local buckling failure mode. The second failure mode is a screening equation in DNV RP F105.

VIV failure mode

- In-line direction

$$F_k(x) = \frac{f_{n,IL}}{\gamma_{IL}} - \frac{U_{c,100\,th}}{V_{R,\ onset}^{IL}}\left(1-\frac{\frac{L}{Dt}}{250}\right)\frac{1}{\bar{\alpha}} \geq 0 \quad (2)$$

- Crossflow direction

$$F_k(x) = \frac{f_{n,CF}}{\gamma_{CF}} - \frac{U_{c,100\,th}+U_{w,1th}}{V_{R,\ onset}^{CF}\,Dt} \geq 0 \quad (3)$$

Local buckling failure mode

- Pi >Pe

$$F_k(x) = 1-\left(Y_m Y_{SC}\frac{|M_{Sd}|}{a_e M_p(t_2)}+\left(\frac{Y_m Y_{SC} S_{sd}(p_i)}{a_e S_p(t_2)}\right)^2\right)^2+\left(a_p\frac{p_i-p_e}{a_e p_b(t_2)}\right)^2 \geq 0 \quad (4)$$

- Pi < Pe

$$F_k(x) = 1 - \left(\Upsilon_m \Upsilon_{SC} \frac{|M_{Sd}|}{\alpha_e M_p(t_2)} + \left(\frac{\Upsilon_m \Upsilon_{SC} S_{sd}(p_i)}{\alpha_e S_p(t_2)}\right)^2\right)^2 + \left(\Upsilon_m \Upsilon_{SC} \frac{p_e - p_{min}}{p_e(t_2)}\right)^2 \geq 0 \qquad (5)$$

Determination of the distribution of random variables to perform this simulation is assisted by EasyFit software. Table 4 shows the distribution and parameters of a random variable.

Table 4. Random Variable Distribution

Random var.	Distribution	Parameter
Gap	Weibull	α = 1.353 β = 0.092 γ = 0.047
Span length	Gen. Extreme	k = 0.028 μ = 9.349 σ = 4.912
Modulus young	Log-Normal	$\mu = 2.1 \times 10^{11}$ C.O.V = 0.05
$U_{w,1th}$	Frechet	α = 1237 β = 0.00117
$U_{w,100th}$	Frechet	α = 1237 β = 0.00117
F_y	Normal	$\mu = 4.48 \times 10^8$ C.O.V = 0.1
F_u	Normal	$\mu = 5.4 \times 10^8$ C.O.V = 0.1

2.4 Risk

Risk analysis is done to determine the vulnerability and consequences of a system against risk and to ensure that the system complies with the applicable rules [4]. Risk is the result of multiplication between probability failures with failure consequences. Risks are usually presented in the form of a risk matrix.

2.5 Risk based inspection

Risk-Based Inspection is a design and optimization method of an inspection scheme based on risk assessment. Risk assessment here relies on previous data, analytical methods, and assessments of people who are experienced in the field [4]. In other words, the RBI uses qualitative and quantitative assessments to prioritize analysis and inspection planning activities [9].

2.6 RBI API RP 580

In API of RP 580, there are six categories of PoF and six categories of CoF. It will obtain a 6x6 risk matrix. CoF which is reviewed in API RP 580 is aspects of safety, environment, and assets.

Table 5. PoF of API RP 580

Possible qualitative rank	PoF
Remote	< 0.00001
Very low	0.00001 to 0.0001
Low	0.0001 to 0.001
Moderate	0.001 to 0.01
High	0.01 to 0.1
Very high	>0.1

Table 6. CoF of API RP 580

Category	Description	Safety	Environment	Economic
I	Catastrophic	Large number of fatalities	major long-term environmental impact	≥$100,000,000
II	Major	A few fatalities	major short-term environmental impact	≥$10,000,000 < $100,000,000
III	Serious	Serious injuries	Significant environmental impact	≥$1,000,000 < $10,000,000
IV	Significant	Minor injuries	Short-term environmental impact	≥$100,000 < $1,000,000
V	Minor	First aid injuries only	Minimal environmental impact	≥ $10,000 < $100,000
VI	Insignificant	No significant consequence		< $10,000

Table 7. Inspection Interval Range

Risk category	Inspection interval range
High	3 years to 5 years
Medium	6 years to 10 years
Low	11 years or greater

2.7 RBI DNV RP F116

In DNV RP F116, there are five categories of PoF and five categories of CoF. So, if presented in the form of a risk matrix, it will be a 5x5 matrix. In determining the scheduling of inspections can be seen in the following equation

$$I = I_R \, C \, D \qquad (6)$$

With ***IR*** is a base inspection interval, ***C*** is the confidence factor of POF and ***D*** is the possible development of PoF.

Table 8. CoF of DNV RP F116

Severity	Safety	Environment	Cost (million Euro)
A	No or superficial injuries	Slightly effect on the environment (<1 BBL)	< 0.01
B	Slightly injury, a few lost workdays	Minor effect No-compliance (<5 BBL)	0.01 – 0.1
C	Major injury, long term absence	Localized effect Spill response (<50 BBL)	0.1 – 1
D	Single fatality or permanent disability	Major effect Significant spill response (<100 BBL)	1 – 10
E	Multiple fatalities	Massive effect large damage area (>100 BBL)	> 10

Table 9. PoF of DNV RP F116

Severity	Description	PoF
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}

Increasing consequences →	Severity	Increasing probability				
		1	2	3	4	5
		Failure is not expected < 10^{-5}	Never heard of in the industry 10^{-5} - 10^{-4}	An accident has occurred in the industry 10^{-4} - 10^{-3}	Has been experienced by most operators 10^{-3} - 10^{-2}	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 1. Base Inspection Interval DNV RP F116

3. RESULTS AND DISCUSSION

3.1 Monte carlo simulation

This simulation was performed to calculate the reliability of the subsea pipeline due to a free span that was considered critical, the largest span has a length of 183 m and a gap of 0.2 m. In the local buckling failure mode Equation (4) is used, because the internal pipe pressure is greater than the external pipe pressure. The monte carlo reliability simulation was carried out as many as 10,000 times the simulation. PoF in the 10,000th simulation is used as the PoF value in the risk calculation.

Table 10. Simulation's Result

No.	VIV			*Local buckling*		
	Number of simulations	Reliability	PoF	Number of simulations	Reliability	PoF
1	1000	0.002	0.998	1000	0	1
2	2000	0.0015	0.9985	2000	0	1
3	3000	0.001	0.999	3000	0	1
4	4000	0.0015	0.9985	4000	0	1
5	5000	0.0016	0.9984	5000	0	1
6	6000	0.0015	0.9985	6000	0	1
7	7000	0.0013	0.9987	7000	0	1
8	8000	0.0013	0.9987	8000	0	1
9	9000	0.0012	0.9988	9000	0	1
10	10000	0.0012	0.9988	10000	0.0001	0.9999

From the simulation that has been done, the value of PoF in fatigue-induced mode due to VIV is 0.9988 and for local buckling failure mode is 0.999. At API RP 580.

PoF fatigue due to VIV and local buckling are included in very high category. Meanwhile, in DNV RP F116 second PoF is included in severity 5.

3.2 Consequences analysis

3.2.1 Safety

Based on the location of the pipeline under the sea, possible failures, both due to fatigue and local buckling, have a small safety impact. The failure of the free span had a small impact on safety when it was reviewed based on the failure of a free span due to buckling [10].

So, it can be said that in the API of RP 580, the safety aspect is included in category VI (insignificant). Meanwhile, in DNV RP F116 the aspect of safety is included in category A.

3.2.2 Environment

The fluid flowing by the subsea pipeline affects the consequences posed for the environment. In this reviewed subsea pipeline, the fluid that is flowing is gas. When the gas is flowing into the leaking pipe, the environmental damage will be very small.

So, it can be said that in the API of RP 580, environmental aspects are included in category VI (insignificant). Meanwhile, in DNV RP F116 environmental aspects are included in category A.

3.2.3 Asset

With the failure of the subsea pipeline, production will cease. This led the company to a loss. It is known that the gas flow rate of the pipe is 70,000 MMBTU and there are 227.94 MMBTU in the subsea pipeline. Production losses ranged from 70,227.94 MMBTU.

If multiplied by the current price of gas per MMBTU, the total loss of $137646.77 or the equivalent of EUR 127209.25 is obtained. In API RP 580, the amount of this loss is categorized in category IV (significant). Meanwhile, in DNV RP F116 This loss is included in category C.

3.3 Risk matrix

From determining the probability of failure and consequences of failure, it can be known the level of risk of each aspect. It is known that the value of PoF against two failure modes has the same category.

Both in API RP 580 and DNV RP F116, then the risk matrix displayed already represents the level of risk of both the failure modes against all three aspects of the consequences reviewed.

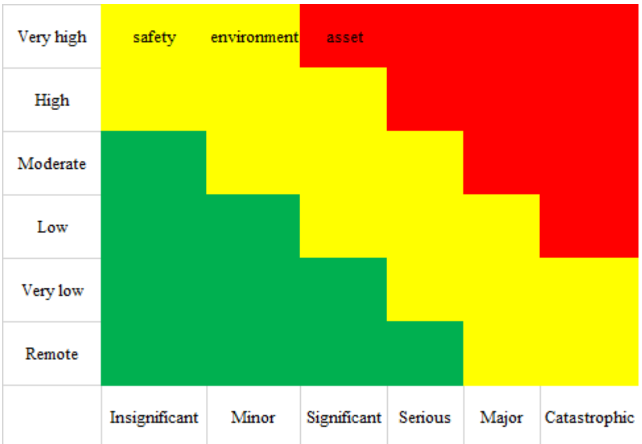

Figure 2. API RP 580 Risk Matrix

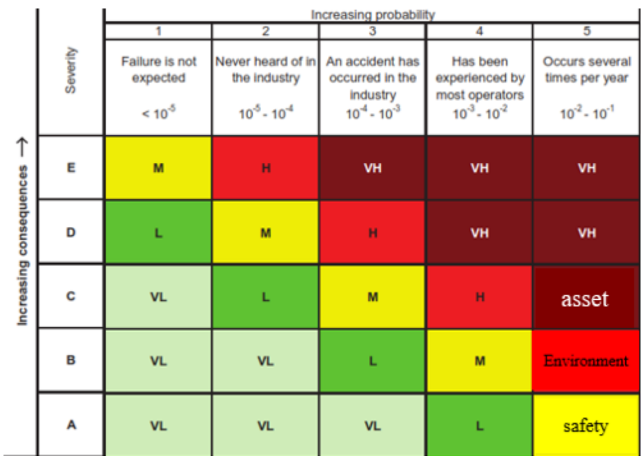

Figure 3. DNV RP F116 Risk Matrix

3.5 Inspections

In determining the next inspection schedule on API RP 580, used table 4 of API RP 2SIM [11]. Whereas, in scheduling inspections with DNV codes RP F116 use equations (6). The value of the based inspection interval for safety aspects (medium category) is 3, and for the environmental aspect (high category) is 1. While other asset aspects in very high category are better to change the pipe right away. There is a significant difference between scheduling inspections with API codes of RP 580 and with DNV RP F116. Scheduling inspection using API RP 580 longer 2-3 years compared with DNV RP F116.

Table 11. Inspection schedule using API RP 580

Aspect	PoF	CoF	Risk	Schedule
Safety	Very high	Insignificant	Medium	6 years
Environment	Very high	Minor	Medium	6 years
Asset	Very high	Significant	High	3 years

Table 12. Inspection Schedule using DNV RP F116

Aspect	PoF	CoF	Risk	Schedule
Safety	5	A	Medium	3 years
Environment	5	B	High	1 year
Asset	5	C	Very High	-

The inspection methods that can be used for checking VIV and local buckling on an undersea pipeline are intelligent pigging and ROV. Intelligent pigging is useful for cleaning pipes and also checking outside and inside diameters of underwater pipes, cracks, and also a dent. Whereas inspection with ROV can collect information regarding visual subsea pipelines and external conditions of the subsea pipelines, cathodic protection, and the possibility of other external disturbances, such as anchors [12].

6. CONCLUSIONS

From the previous calculations and analyses, it can be concluded that based on API RP 580, scheduling inspection from the aspect of safety and environmental must be inspected every 6 years, while from the ascpect of asset must be inspected in 3 years. Scheduling inspection based on DNV RP F116 must be conducted once in 3 years from the safety aspects, once a year from the environmental aspects. While, it would be better to change the pipe considering the aspect assets. The inspection methods suitable for the free spanning pipeline are intelligent pigging and ROV.

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