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Technical Report
Risk Assessment of Subsea Gas Pipeline Due to Port Development Located at Narrow Channel

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Abstract

Background and Objective: Offshore gas pipeline is one of the methods to distribute gas from gas field to receiving facility. There is 16" subsea export gas pipeline exporting gas from Poleng gas field to ORF (Onshore Receiving Facility) in Gresik. Due to plan of port development in Socah-Bangkalan, the pipeline segment located in KP 49-55 could be eventually affected by the development plan both during construction of the port and during its operation. This study aimed to assess the risk possessed by the export gas pipeline due to port development plan during the construction and operation period. **Materials and Methods:** The ranks of frequency and consequences were mapped into risk matrix according to DNV-RP-F107. The mitigation was selected by implementing Multiple Attribute Decision Making (MADM) approach using Analytical Hierarchy Process (AHP) method. **Results:** Based on the result, during construction period, risk profiles laid in acceptable and ALARP regions. These mean that technically in practical, the risk still acceptable and no further mitigation was required for hazard possess by the pipeline in acceptable and ALARP regions. During operation of Jetty, the risk to pipeline was unacceptable, except for hazard of dropped and dragged anchor caused by the tugboat. The most preferable pipeline risk mitigation method was lowering the pipeline segment located in front of the jetty to 2 m below the water depth of final capacity development of port and installing additional of navigational aid (yellow buoy) to indicate the existence of the pipeline. **Conclusion:** Therefore, the risk assessment should be taken for every activity that could possibly affect the offshore facility in order to ensure the safety during the process and against the pipeline, so the mitigation can be taken when the risk was unacceptable.

Key words: Risk assessment, DNV-RP-F107, port development, analytical hierarchy process method, export gas pipeline

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The energy consumption in the world is predicted to increase especially the consumption of natural gas as energy source. Natural gas remains as attractive choice for electric power sector because of its fuel efficiency and cleaner fuel to reduce carbon dioxide (CO_2) emissions[1]. In Indonesia especially Java, the demand for natural gas will increase due to the expansion in gas-based electricity generation[2]. From the production side, Indonesia's gas industry is playing a vital role in energy sector because gas production in Indonesia is ranked in 10th in terms of global gas production[3]. One of the gas production field is Poleng field which located offshore west of Madura Island and gas receiving facilities located in Gresik, East Java. The gas must be transported from gas field to receiving facility. The well-known method for transporting the gas is by pipelines because it can transport large quantities of natural gas[4]. Therefore, gas from Poleng filed is exported by 16" subsea gas pipeline to onshore receiving facilities. Unfortunately, those pipeline segment located in KP (Kilometer Point) 49-55 will be eventually affected by the port development plan near location that is Socah-Bangkalan, Madura (Fig. 1). The port development project is considered providing threat to the 16 export gas pipeline either during the construction period of the seaport city and during its operation. The failure accident of pipeline is significantly raising the problems and cause impacts on economic loss including cleanup and recovery cost, people and damage to the environment[5,6]. Hence, the safety of subsea gas pipeline is very concern issue in this case.

The assessment risk of pipeline used four parameters to obtain the relative risk index. The parameters are third party, corrosion, design and incorrect operation[7]. Those parameters can be categorized into 2 factors which cause the damage against the pipeline, that is external and internal causative factor. One of the most significant cause of pipeline distraction is corrosion[8]. However, it is also important to protect the offshore pipeline failure from third party damages due to high human activity on the sea. The third party defined as any accident result damage to the pipeline due to external activities that not corresponding with the pipeline[7]. The third party activities shall be classified as interference loads include trawl interference, anchoring, vessel impacts and dropped objects, but the most common factors of third party damage are from impact and offshore anchoring activities[6,9]. Refers to research conducted by Mulyadi *et al.*[10], Health and Safety Executive (HSE) and Pipeline and Riser Loss of Containment (PARLOC) reports that there were 11 recorded incidents of anchor damage for over 25,000 km of subsea pipelines in the North Sea area during 1996-2001.

Fig. 1: Location of port development

In general, this study was aimed to assess the risk possessed by the export gas pipeline due to port development plan during the construction and operation period which likely exposed the risk of pipeline damaged by dragged anchor using DNV RPF-107 (Risk Assessment of Pipeline Protection). The DNV-RP-F107 was the recommended practice that describe the risk assessment related to accidental scenario during the external activity developed by Det Norske Veritas (DNV). Should the assessment results found that the risk was not acceptable, some recommendations will be provided either to protect the pipeline or relocating them.

MATERIALS AND METHODS

Risk is a parameter used to evaluate the significance of hazards in relation to safety. Hazards are the possible events and conditions that may result in severity. Risk is normally evaluated as a function of probability occurrence for hazard and severity of possible consequences for that particular hazard[11].

The methodology applied to this study was the risk assessment process. This process consisted of four basic steps[12]:

- Hazard/risk identification
- Likelihood/probability/frequency assessment
- Consequence assessment
- Risk assessment and mitigation if the risk was unacceptable

Hazard identification is a qualitative review of possible accident that may occur. In order to select failure cases for quantitative modelling, it will be evaluated by HAZID (Hazard Identification). The HAZID is a systematic review of possible causes and consequences of hazardous event[13]. This

Table 1: Frequency ranking according to DNV-RP-F107[14]

Category	Description	Annual frequency
1 (Low)	So low frequency that event considered negligible	$<10^{-5}$
2	Event rarely expected to occur	$10^{-4}> 10^{-5}$
3 (Medium)	Event individually not expected to happen, but when summarized over a large number of pipelines have the credibility to happen once a year	$10^{-3}>10^{-4}$
4	Event individually may be expected to occur during the lifetime of the pipeline (Typically a 100 year storm)	$10^{-2}>10^{-3}$
5 (High)	Event individually may be expected to occur more than once during lifetime	$>10^{-2}$

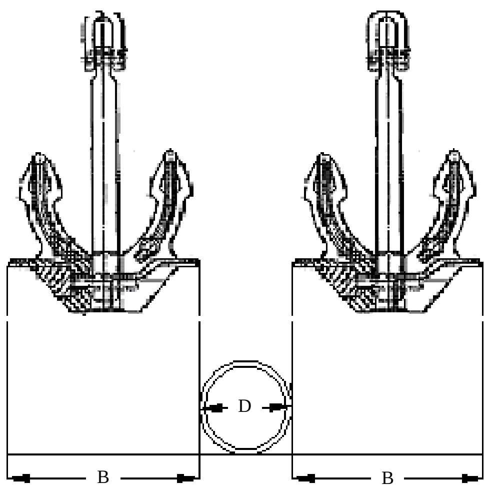

Fig. 2: CODZ area[14]

study performs risk assessment of gas pipeline due to the port development project (during construction and operation) according to DNV RPF-107 (Risk Assessment of Pipeline Protection).

For the threats carried forward, a Failure Mode and Effect Assessment (FMEA) are carried out to identify the failure modes for each of the threats identified. Location specific threats are identified. The results from the FMEA form the basis for the Risk Assessment analyses. The risk assessment includes both frequency and consequence analysis.

Frequency assessment: The risk level was determined by combining two important parameters, the probability of the event and the consequence of the event. Frequency analysis was used to estimate how likely it was that the different accident or hazards will occur (i.e., the probability of occurrence)[11]. The probability of dropped object on pipeline was product of probability of dropped object and probability of dropped object on CODZ (Critical Object Drop Zone) as shown in Fig. 2. The CODZ defined as pipeline diameter added by twice of the object width.

One of the potential threats to pipeline was drag anchor. Drag anchor occurred through a sequential possibility of event or join probability. Those events are:

- Probability of anchor dropped close to the CADZ (Critical anchor damage zone)
- Probability of anchor dragged after it is dropped

Probability of the anchor dragged onto the probability of ship sinking on the pipeline can be calculated by a join probability of:

- Probability of ship located in the critical sinking zone (CSZ)
- Probability of the ship will sink
- Exposed pipeline
- Though the risk on pipeline due to ship sink only occurs to unburied pipeline (on seabed), to simulate the effect of the ship sink to the pipeline, a sequence of trench depth will be analyzed

The result of the frequency assessment is then to be classified into the frequency ranking as per DNV-RP-F107 shown in Table 1.

The probability of a dropped object puncturing live equipment may be estimated by an energy approach, using the sizes of lifted objects, the probable drop height and the designed impact resistance of protective decks. However, several studies had shown the contribution to leak frequencies from dropped objects to be low enough to justify neglecting the hazard.

Consequence assessment: All approaches used to estimate the consequence due to dropped anchor, dragged anchor and ship sinking was performed as per DNV-RP-F107. The result of the consequence assessment was then to be classified into the consequence ranking as per DNV-RP-F107 shown in Table 2. The ranking in Table 2 described the severity level of steel pipelines damage.

Most impact for steel pipelines results the dent shape. The dent-absorbed energy relationship is given in Eq. 1 and the schematic of dent prediction model is presented in Fig. 3. It is modeled as a knife-edge load perpendicular to the pipeline and the indenting pipe cover the entire cross section[14]:

Table 2: Impact capacity and damage classification for steel pipelines[14]

		Conditional probability					
Dent/diameter (%)	Damage description	D1	D2	D3	R0	R1	R2
<5 (Level 1)	Minor damage	1.0	0.00	0.00	1.00	0.0	0.00
5-10 (Level 2)	Major damage Leakage anticipated	0.1	0.80	0.10	0.90	0.1	0.00
10-15 (Level 3)	Major damage Leakage and rupture anticipated	0.0	0.75	0.25	0.75	0.2	0.05
15-20 (Level 4)	Major damage Leakage and rupture anticipated	0.0	0.25	0.75	0.25	0.5	0.25
>20 (Level 5)	Rupture	0.0	0.10	0.90	0.10	0.2	0.70

D1: Damage requiring neither repairs or resulting in any release of hydrocarbons, D2: Damage requiring repairs, but not leading to release of hydrocarbons, D3: Damage leaking to release of hydrocarbons or water, R0: No release, R2: Release from small to medium holes on the pipe wall, R2: Release from ruptured pipelines. Full rupture will lead to a total release of the volume of the pipeline and will condition until the pipeline is isolated

Table 3: Drag coefficient[14]

Cat. No.	Description	C_D	C_a
1,2,3	Slender shape	0.7-1.5	0.1-1.0
4,5,6,7	Box shape	1.2-1.3	0.6-1.5
All	Misc. Shape (spherical to complex)	0.6-2.0	1.0-2.0

C_D: Drag coefficient, C_a: Drag coefficient of added mass

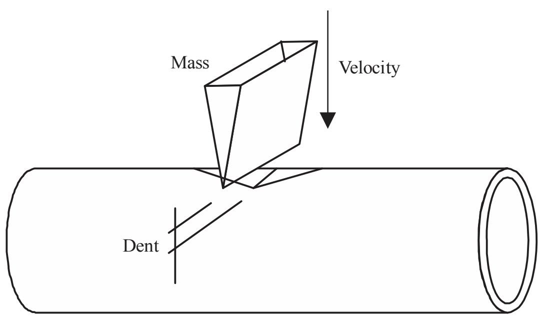

Fig. 3: Dent prediction model[14]

$$E = 16\times\left(\frac{2\pi}{9}\right)^{\frac{1}{2}}\times m_p\times\left(\frac{D}{t}\right)^{\frac{1}{2}}\times D\times\left(\frac{\delta}{D}\right)^{\frac{3}{2}} \quad (1)$$

Where:

- E = Absorbed energy
- D = Pipeline outer diameter (OD)
- m_p = Plastic moment capacity ($0.25\times SMYS\times t^2$)
- d = Dent depth
- t = Pipe thickness

Impact resistance of concrete coating is calculated as follow:

$$E = Y\times b\times h\times x_0 \quad (2)$$

Where:

- Y = Crushing strength of concrete 3 x 42 = 126 MPa
- $b\times h$ = Area of impacting object 0.2 m$\times$0.2 m: 0.04 m^2 [point load]
- x_o = Impacting depth, i.e. concrete coating thickness (mm)

The following equation is used to calculate impact energy of dropped object on top of pipeline:

$$[m-(V\rho_{water})]g = \frac{1}{2}\rho_{water}\times C_D\times A\times v_T^{\,2} \quad (3)$$

Where:

- m = Weight of dropped object (kg)
- g = Gravitational acceleration (9.81 m sec^{-2})
- V = Volume of dropped object (m^3)
- ρ_{water} = Sea water density (1025 kg m^{-3})
- C_D = Drag coefficient
- A = Drop object projected area (m^2)
- v_T = Drop object terminal velocity (m sec^{-1})

Based on DNV-RP-F107, drag coefficient shown in Table 3. For calculation of consequences, value of 1.0 used as recommendation from DNV-RP-F107.

Effective kinetic energy (EE) defined as follow:

$$EE = ET+EA \quad (4)$$

$$EE = \frac{1}{2}(m+m_a)\times v_T^2 \quad (5)$$

Where:

- m_a = Added mass (kg)
  = $\rho_{water}\times Ca\times V$
- Ca = Drag coefficient of added mass

Kinetic energy of dropped object is calculated as follow:

$$ET = \frac{1}{2}m\times v_T^2 \quad (6)$$

Where:

- m = Object mass (kg)
- V_T = Terminal velocity of dropped object (m sec^{-1})

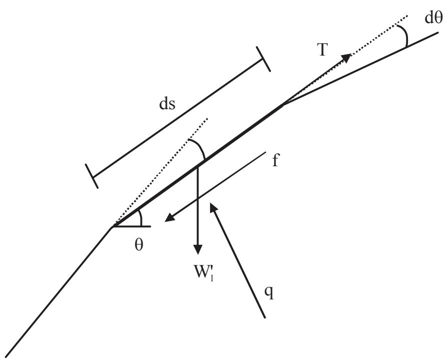

Fig. 4: Stresses at a trawl line segment in soil[15]

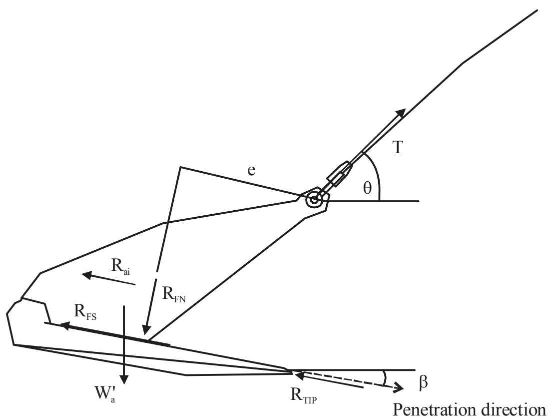

Fig. 5: Principal soil reaction forces on a fluke[15]

From above equations, we have:

$$ET = \left(\frac{m \times g}{C_D \times A}\right) \times \left(\frac{m}{\rho_{water}} - V\right) \quad (7)$$

Consequence analysis of dragged anchor in this study adopts the method of consequence assessment for trawling activities in a certain pipeline zone. Therefore, the trawl in the next description is assumed as an anchor. Two standards of consequence assessment of the pipeline due to anchor drag are DNV-RP-E301 and DNV-RP-E302. Refers to DNV-RP-E301, the stress on trawl line element in the soil are shown schematically in Fig. 4 which q is the normal stress and f is the unit soil friction.

The friction force of the trawl line to top of seabed can be calculated as:

$$\Delta R_{fric} = \mu \times Wl' \times L_s \quad (8)$$

Where:

Ls = Length of line tension
Wl' = Weight of trawl per unit length
μ = Friction coefficient

The normal stress can be calculated by:

$$q = N = Wl'/\cos\theta \quad (9)$$

The undrained shear strength (direct simple shear strength):

$$S_u = q/N_c \;\; Nc = 11.5 \quad (10)$$

The undrained unit friction acting on trawl line can be calculated as below:

$$f = \alpha_{soil} \times S_u \quad \alpha_{soil} = 0.3 \quad (11)$$

The Line Tension (dT) Over One Element Length (ds) can be calculated as below:

$$\frac{dT}{ds} = -f \times AS \times -W_l^{'}\theta \quad (12)$$

$$AS = p \times d \quad (13)$$

$$dT = (-f \times AS - W1_l^{'} \times \sin\,)ds \quad (14)$$

$$T = \int_0^{1,5} (-f \times AS - W_l^{'} \times \sin\theta)ds \quad (15)$$

$$T = [-f \times AS(s) - W_l^{'}(s) \times \sin\theta]_0^{1,5} \quad (16)$$

As Fig. 5 explained the necessary equilibrium equations for penetration direction coincides with fluke penetration direction. The horizontal and vertical equilibrium should deal with following equations.

Horizontal equilibrium:

$$T\cos\theta = \sum_{i=1}^{N} R_{ai}\cos\beta + R_{FS}\cos\beta + R_{TIP}\cos\beta + R_{FN}\sin\beta \quad (17)$$

Vertical equilibrium:

$$T\sin\theta = R_{FN}\cos\beta + W_l^{'} - \sum_{i=1}^{N} R_{ai}\sin\beta + R_{FS}\sin\beta + R_{TIP}\sin\beta \quad (18)$$

Force resultant:

$$T = \sqrt{T_H^2 + T_V^2} \quad (19)$$

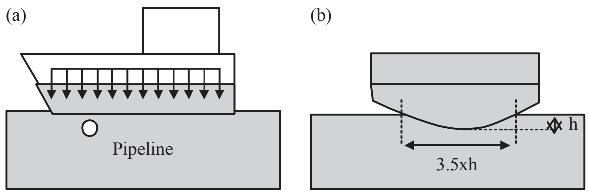

Fig. 6(a-b): Acting forces on ship sinking, (a) Line-load onto pipeline and (b) Penetration depth

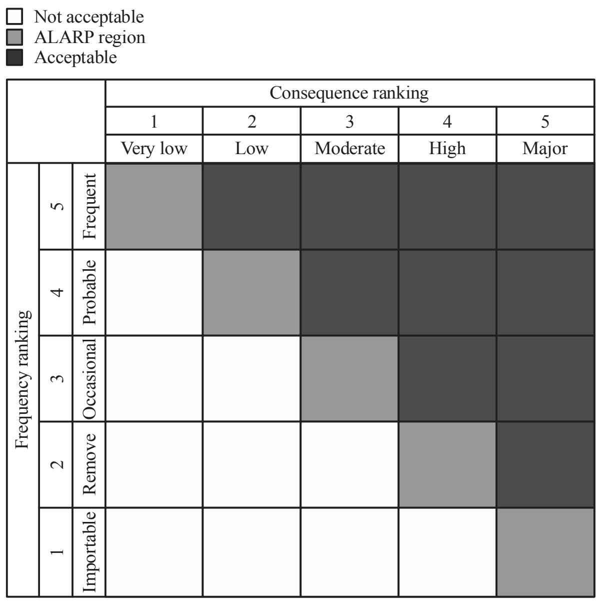

Fig. 7: Risk matrix according to DNV-RP-F107[14]

Where:

T,θ = Tension and corresponding orientation of trawl line at the shackle
RFN = Soil normal resistance at the trawl
RFS = Soil sliding resistance at the trawl
RTIP = Tip resistance at the trawl
Rai = Soil resistance at the remaining components of the trawl (separated through trawl geometry)
WT = Submerged trawl weight
B = Penetration direction of trawl

Ship sinking consequence assessment: To simplify the purpose of consequence assessment for ship sinking, the complexity of vessel sinking and subsequent pipeline damage need some assumptions. It was assumed that the vessel will sink relatively slowly in the horizontal position and settle relatively gently onto seabed and/or pipeline. Others assumption are there are no air pockets in the sunken vessel and all the steel have a mass density of 7850 kg m^{-3}. The load from the sinking vessel is considered to be a quasi-static load governed by its submerged weight. A dynamic amplification factor (DAF) of t.2 was applied to account for moderate dynamic effects. The vessel DWT was used in calculations and was a conservative estimate of submerged weight.

Figure 6a showed that an exposed pipeline on the seabed is assumed that more than half this load is carried by the pipe. If the pipeline has been lowered into the seabed and covered, the load from the vessel will be distributed over the length of the vessel acting as a point load. Figure 6b presented the load per meter. It may be estimated from the Length of the vessel, multiplied by a factor of 0.9 to account for the rounded stem and bow. It was necessary to establish the static capacity of the pipeline subjected to a point load at 12 o'clock for an exposed pipeline and line load for a buried pipeline. It was used to determine whether the load imposed by a sinking vessel is acceptable to the

The pipe section as two-dimensional ring is considered, then the maximum bending moment is:

$$M_{load} = \frac{P \times R}{p} \quad (20)$$

Where:

R = Radius of pipe
P = Pressure load

The maximum capacity of the pipe to be given as a fully plasticized wall is considered as:

$$M_{capacity} = 0.25 \times SMYS \times t^2 \quad (21)$$

Where:

SMYS = Specified Minimum Yield Strength
t = Wall thickness

Risk matrix (DNV-RP-F107): The risk level is determined by combining the probability of occurrence and the consequence of the event. DNV-RP-F107 "Risk Assessment of Pipeline Protection" is adopted as an assessment protocol to determine the risk rating of identified hazards. As shown in Fig. 7 that the risk matrix consists of 5×5 risk matrix to determine a risk rating. The risk level can be obtained and evaluated by plotting the frequency and consequence in the risk matrix. Figure 7 showed that the color of each area indicate the acceptable risk level. If the risk level is not acceptable, then the mitigation should be taken to reduce the risk level[14].

Case study: Case study of this risk assessment is applied in subsea export gas pipeline distributed gas from Poleng gas field to ORF in Gresik due to the port development. Considering the position of the port with respect to

Fig. 8: Flow of material during construction
1: Work shop area, 2: Trestle, 3: Jetty

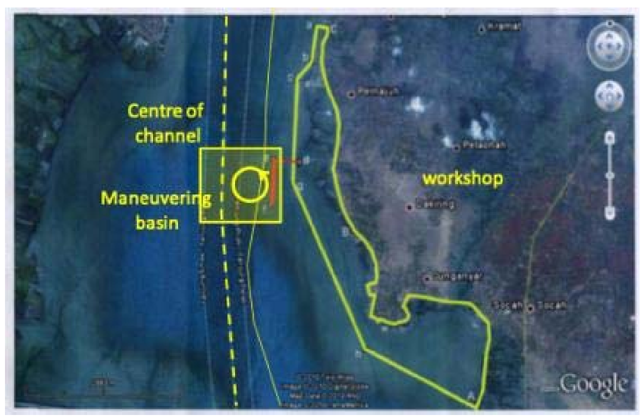

Fig. 9: Position of maneuvering basin of port to gas pipeline

the 16 pipelines, it was shown that the development of port provides impact to the pipeline in two conditions below:

- **During construction:** Several barges and tugboats are operated during construction for material mobilization or for piling and other construction activities. The scenario of material flow during the construction is described in Fig. 8. Since no information of construction plan is obtained, this study will consider the flow of material and construction
- **During operation:** No frequency visit of vessel is obtained to carry out this study. However, considering the position of the jetty and the channel then it is understood that the operation of the port will certainly affect the pipeline as shown in Fig. 9

RESULTS

Hazard identification: Based on design information, admiralty chart, previous project's report and information from some sources, the hazard identification (HAZID) identify the threat that could affect the integrity of the pipeline. By performing threat screening worksheet, a list of potential threat is obtained and the threats are:

- Vessel grounding (crossing part of pipeline)
- Vessel sinking
- Anchor drop/dropped objects

The HAZID analysis presented above that resulted in 3 potential threats, is then utilized in determining hazard compatibility. The compatibility matrix is provided in Table 4.

Result of frequency assessment: Mainly the frequency analysis is done by implementing joint probability method. Several scenarios are developed to analyze frequency of hazards that affect the pipeline integrity during construction of trestle and Jetty as well as during operation of Jetty after completion of construction. There are three main scenarios developed for analyzing frequency of hazards such as:

Fig. 10: Scenario uses for frequency analysis during construction of jetty (No. 3)
1: Work shop area, 2: Trestle, 3: Jetty

Fig. 11: Scenario uses for frequency analysis during construction of trestle (No. 2)
1: Work shop area, 2: Trestle, 3: Jetty

Table 4: Hazard compatibility

	Construction			Operational	
Hazard	Tug boat	Work barge	Tug boat	10000 DWT	40000 DWT
Dropped anchor	√	√	√	√	√
Dragged anchor	√	√	√	√	√
Ship sinking	√	√	√	√	√

Scenario 1: Construction period of jetty including installment of mooring dolphin

Scenario 2: Construction period of trestle that connected jetty

Scenario 3: Operation period of Jetty after completion of construction.

Detail calculation of annual frequency of hazard will be given based on all hazards related to each scenario.

Frequency analysis during construction of jetty: In this scenario, hazard that affect the pipeline integrity may cause by the movement of material from workshop to construction site. The possible hazards can be dropped anchor, dragged anchor and ship sinking. The route of crane barge and tug boat for transporting material from workshop to construction location of jetty is shown as are number 3 in Fig. 10. Since distance between constructions site of jetty to the pipeline (approximately 500-600 m) hazard due to piling activity is negligible.

Frequency analysis during construction of trestle: In this scenario, hazard due to construction period of trestle that connected jetty mainly affected by duration of crane barge and tug boat operated above and in vicinity of pipeline location. Figure 11 showed the illustration of activity of crane

Fig. 12: Scenario uses for frequency analysis during operation Jetty

Table 5: Summary of frequency analysis

	Ranking frequency								
	Construction jetty			Constr. trestle jetty			Operation of jetty		
	Vessel speed (knot)			Vessel speed (knot)			Vessel speed (knot)		
Threat description	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
Dropped anchor									
Tug boat	1	1	1	1	1	1	2	2	2
Crane barge	1	1	1	1	1	1	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2
Dragged anchor									
Tug boat	1	1	1	1	1	1	2	2	2
Crane barge	1	1	1	1	1	1	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2
Vessel sinking									
Tug boat	1	1	1	1	2	2	2	2	2
Crane barge	1	1	1	1	2	2	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2

barge during construction of trestle. The possible hazards that may affect the pipeline integrity are: Dropped and dragged anchor (barge and tug boat), dropped object (PCI Girder, concrete spun pile, steel spun pile, slab precast and diaphragm) and ship sinking (crane barge and tug boat). Ground instability due to piling activity near the pipeline may also considered in analysis.

Frequency analysis during operation of jetty: To approach and depart from port/jetty, vessels maneuver in water basin and assisted by tug boat. During maneuver in water basin, dropping anchor in all condition is not allowed since port area is a restricted/controlled area. In this study, dropped and dragged anchor during operation of jetty applicable only for tug boat that assist the vessels while approaching and departing the port/jetty. In the same words, it is assumed that threats due to dropped and dragged anchor of vessels are not considered in risk assessment due to anchorage restriction in port/jetty area. Figure 12 showed scenario for frequency analysis during operation of jetty.

Summary on frequency analysis: Table 5 showed summary of frequency analysis for all applicable hazards identified during the study. The ranking frequency i.e., 1 describes the level of frequency is at the low level and has the annual frequency is not less than 10^{-5}. The frequency during the operation of jetty has the higher level than the frequency during the construction of jetty.

Table 6: Summary of consequence analysis

	Construction jetty			Constr. trestle jetty			Operation of jetty		
	Vessel speed (Knot)			Vessel speed (Knot)			Vessel speed (Knot)		
Threat description	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
Dropped anchor									
Tug boat	1	1	1	1	1	1	1	1	1
Crane barge	1	1	1	1	1	1	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
Dragged anchor									
Tug boat	1	1	1	1	1	1	1	1	1
Crane barge	1	1	1	1	1	1	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
Vessel sinking									
Tug boat	5	5	5	5	5	5	5	5	5
Crane barge	5	5	5	5	5	5	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5

Result of consequences analysis: The consequences analysis for pipeline damage as the impact of dropped anchor, dragged anchor, ship sinking and dropped object were conducted based on methodology outlined in DNV-RP-F107. It provides a consistent summary of generally accepted practice. The impact damage is assessed based on the energy balance approach where the available energy from impacting object is compared to the energy required to produce a dent. The dent size, expressed as a percentage of overall the pipeline diameter, is an indication as to the likelihood of a leak or rupture as methodology.

Table 6 showed summary of consequence analysis conducted in this study for dropped anchor, dragged anchor, ship sinking and dropped objects. The consequence analysis includes all vessels to be used in construction of trestle, construction of jetty, vessels to be used in operation after completion of jetty.

Risk assessment: The frequency analysis of hazard and its consequence analysis according to DNV-RP-F107, "Risk Assessment of Pipeline Protection". It developed based on existing condition activities during construction and operation of jetty. Ship calls are estimated 10 ships will be served at inner side of jetty having size of 10000 DWT and 5 ships at the outer side of jetty having size of 40.000 DWT. Those scenarios are used to develop the frequency model and consequence model for gas pipeline. The risks of pipeline due to those scenarios are represented using 5×5 risk matrix referred to DNV-RP-F107.

Table 7 showed the summary of risk profiles of all hazards during construction of jetty, construction of trestle and operation of jetty.

As shown in Table 7 that during construction period, risk profiles lay in acceptable and ALARP regions. These mean that technically in practical, the risk still acceptable and no further mitigation was required for hazard possess by the pipeline in acceptable and ALARP regions.

However, during operation of jetty the risk to pipeline was unacceptable, except for hazard of dropped and dragged anchor caused by the tug boat. Therefore, risk mitigation should take place to shift the risk from unacceptable to acceptable region.

Selection of mitigation methods: As described previously, the risk of the pipeline during operation of port is unacceptable. The selection is carried out by implementing Multiple Attribute Decision Making (MADM) approach using Analytical Hierarchy Process (AHP) method. The analytic hierarchy process (AHP) is theory of measurement through pairwise comparison and relies on the judgements of expert to derive priority scale[16]. It was developed by Saaty[16] in the 1970s and has been extensively studied and widely applied in many fields of study.

To make a decision using AHP, the following step should be accomplished[16]:

- The problem in AHP is modeled using decision hierarchy. The hierarchy has structure from top with the goal of the decision, then the element consists of the criteria for evaluating the alternatives and the lowest level as a set of the alternatives

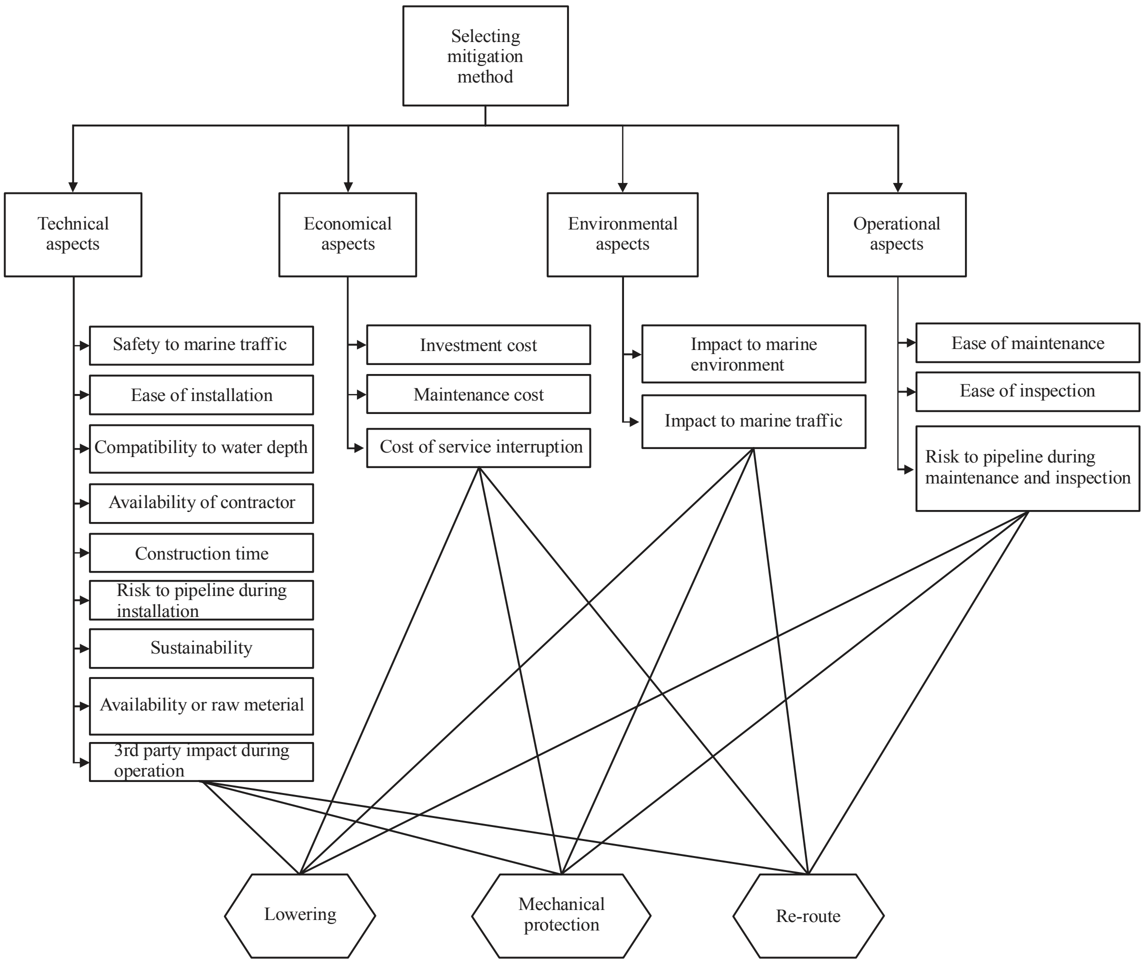

Fig. 13: Selection hierarchy

- Construct a set of pairwise comparison matrices to compare the elements in the level with respect to each element in an upper level
- Make comparisons to weight the priorities. The comparison is measured using a scale of numbers that indicates how many times more important one element is over another element with respect to the criterion which they are compared
- AHP provide to check the inconsistency of the judgement
- Finally, the final decision is obtained based on the ranking of the result

Three alternatives of pipeline risk mitigation method are used as the basis of selection model. Those methods are:

- **Alternative 1:** Lowering pipeline
- **Alternative 2:** Mechanical protection
- **Alternative 3:** Re-route pipeline (to onshore)

Three main attributes and sub-attributes were then used as shown in the Fig. 13.

As shown in Fig. 14, lowering pipeline was the most preferable rectification method with a selection weight of 35.2%, followed by pipeline re-route (32.9%) and mechanical protection (31.9%). It was recommended to use lowering pipeline as a pipeline risk mitigation method.

DISCUSSION

This study presented the risk assessment of subsea gas pipeline due to port development. The result of hazard identification as the first step in this risk assessment presents the hazards that potentially occur during the activity are dropped object, dragged anchor and ship sinking. Then every hazard was evaluated to interpret the risk using practical recommendation namely DNV RP-F104. The frequency assessment indicates that the dropped object and drag frequency from anchor is high during the operation of jetty.

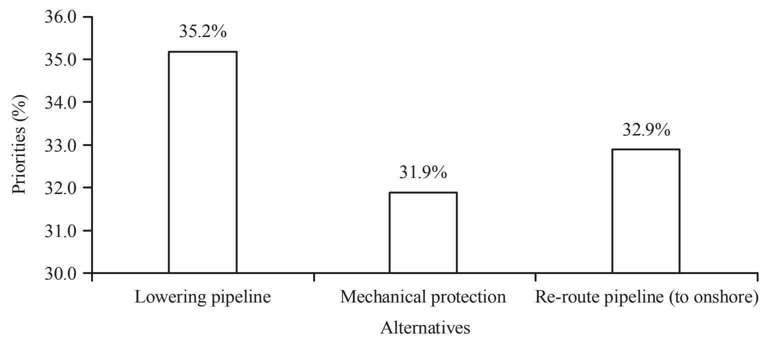

Fig. 14: Preference degree of each alternative

Table 7: Summary of risk profiles due to dropped anchor, dragged anchor and ship sinking

	Construction jetty			Constr. trestle jetty			Operation of jetty		
	Vessel speed (knot)			Vessel speed (knot)			Vessel speed (knot)		
Threat description	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
Dropped anchor									
Tug boat	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(2,1)	(2,1)	(2,1)
Crane barge	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)
Dragged anchor									
Tug boat	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(2,1)	(2,1)	(2,1)
Crane barge	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)
Vessel sinking									
Tug boat	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	(2,5)	(2,5)	(2,5)
Crane barge	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	N/A	N/A	N/A
10000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)
40000 DWT ship	N/A	N/A	N/A	N/A	N/A	N/A	(2,5)	(2,5)	(2,5)

Compare to other study related to external impact in pipeline risk assessment, the frequency tends to vary with the different scenario. Previous study mentioned that the trawler impact has high frequency, instead of dropped anchor impact frequency because the location of the study near trawling zone[17]. By Liu *et al*.[18], this result is not much different with the report presented by MacDonald[19], which stated that anchor and trawling accidents to offshore pipelines occur frequently, 37% (19/52) and 44% (23/52), respectively. Other previous research also showed that in Madura Strait, the estimated dragged anchor accident frequency for merchant ship categories has the high frequency ranking. For other ships has values in the low frequency ranking of level 2 in DNV Risk matrix[10]. Based on several previous researches and current study, the estimated value of accident frequency is strongly depended on number ships movements near the pipeline.

For the consequence analysis, the level of damage to the pipeline is determined by several factors such as length of ships, weights of ships anchors and ship's speed. The result in this study is in line with the previous research that the pipeline damage is proportional to the factors. In other research, length, weight and speed of ships are important value to determine the vertical distance of dragged anchor. This implied that the higher velocities, the tow depth is less[20]. Although the previous research performed the different method, the results shows similar value.

In decreasing the risk level become acceptable, the mitigation was selected using Analytical Hierarchy Process (AHP) method. AHP successfully defines the optimum alternatives relies on the judgements of expert and it is able to check inconsistency[21]. The most preferable mitigation according to AHP results is lowering pipeline as a pipeline risk mitigation method. According to previous researches[22], one of type of pipeline damage prevention due to third parties is sleeving the pipeline with coating. It certainly provides the pipeline by additional layer of protection, but it does not identify the contents of the underlying pipeline. However, the third-party activity does not aware until the pipeline is damaged. Mechanical protection also has maximum energy absorption[14] about 10 kJ. While, lowering the pipeline can be adjusted according to depth of anchor penetration so trenching may reduce risk[23]. Even though the lowering pipeline is a high-risk project, but it is feasible to be carried out and effective solution.

This study related to the safety of offshore pipeline is important issue due to effect against pipeline damage. The result of the study indicates that during the operational of jetty, the risk is relatively high. Therefore, the stakeholder involved in the case study should be aware that the port development and during the operational of jetty threat the pipeline.

In the further study, it is necessary to implement Automatic Identification System (AIS) because AIS provide more accurate data about traffic volume of ships. The frequent of movement ship significantly affects the estimated value of accident frequency, so that the result can be more approaching the actual condition. In addition, validation result should be performed. The validation could be conducted by comparing the estimated value of frequency and consequence with actual accident error if the data is available.

CONCLUSION

The risk to pipeline due to all potential hazards (dropped anchor and dragged anchor) during construction period of jetty and trestle is acceptable, whilst the risk due to ship sinking is ALARP.

The risk to pipeline due to all potential hazards (dropped anchor, dragged anchor and ship sinking) during operational period of jetty and trestle is unacceptable.

The most preferable pipeline risk mitigation method is by lowering the pipeline segment located in front of the jetty of port, to 2 m below the water depth of final capacity development of port and installing additional of navigational aid (yellow buoy) indication the existence of the pipeline. This will eliminate all possible hazards to pipeline permanently.

SIGNIFICANCE STATEMENT

This study analyzed the risk assessment of subsea gas pipeline against the damage due to port development activity and during the operational of jetty. The result of the study provides the description about the important of ensure the safety of pipeline and also gives recommendation to mitigate if the risk lies on unacceptable ranking based on Multiple Attribute Decision Making (MADM).

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