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RISK ANALYSIS OF DROPPED ANCHOR IMPACT ON SUBSEA PIPELINES IN NATUNA

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Abstract

Energy is a fundamental element in economic and social development, with oil and natural gas remaining the primary energy sources in Indonesia. To support the distribution of hydrocarbons from production facilities to onshore locations, subsea pipelines serve as vital infrastructure in the upstream oil and gas industry. However, subsea pipelines face various external risks, including dropped ship anchors, which can cause significant damage both technically and environmentally. This study aims to analyze the risk level of dropped anchors on subsea pipelines in Natuna. The methodology involves data collection related to pipeline characteristics, vessel traffic, and anchor types. Consequence analysis is conducted by calculating pipeline dent levels due to anchor kinetic energy based on the DNV-RP-F107 guideline. The results show that the anchor impact energy on the pipeline is approximately 3,94 kJ, placing the pipeline consequence level in the <5% dent/diameter category. Risk assessment using a risk matrix indicates that the risk level remains within the ALARP (As Low As Reasonably Practicable) threshold, meaning the risk is acceptable with reasonable mitigation measures. The findings suggest that although dropped anchors can cause pipeline deformation, the resulting damage remains within safe limits. However, to further reduce potential risks, additional mitigation measures are required, such as vessel traffic monitoring, designated anchor-free zones, and enhancing pipeline resilience against external impacts.

Keyword: subsea pipeline, dropped anchor, risk analysis, mitigation, DNV-RP-F107, ALARP

1. INTRODUCTION

Energy is a fundamental element in the economic and social development of every country, including Indonesia, which remains highly dependent on oil and natural gas as its primary energy sources [1]. To meet the growing energy demands, Indonesia continues to explore oil and gas resources both onshore and, more recently, in offshore areas. The use of subsea pipelines as a means of transporting oil and gas is a common practice in the upstream oil and gas industry [2]. These pipelines serve as critical infrastructure, facilitating the transportation of hydrocarbons from offshore production facilities to onshore distribution points.

However, subsea pipelines are exposed to various external risks, which not only pose significant environmental threats but also lead to substantial financial losses for companies in the event of damage. Pipeline failures result in additional costs, including spill cleanup, facility repairs, and potential compensation payments [3-6]. The complexity of managing these risks is further heightened by multiple external factors that contribute to pipeline failure, ranging from marine activities to design and operational errors.

Since the 1980s, there has been increasing concern regarding subsea pipelines, particularly following several incidents of pipeline failures that have caused severe environmental damage. Despite numerous recorded incidents, the long-term consequences of these failures have not been thoroughly investigated, necessitating further research to fully understand their impact [7-9]. The primary causes of subsea pipeline failures include third-party interference, corrosion, design flaws, and operational errors.

Third-party interference is a significant factor contributing to pipeline failure, encompassing activities such as fishing, commercial shipping—including risks from emergency anchoring, dragged anchors, fallen containers, and sunken vessels—as well as construction vessel operations [10, 11]. In areas with dense oil and gas production activities, the risk of major pipeline damage is amplified. Common damages such as deflections and leaks not only create technical challenges but also pose persistent environmental hazards. Therefore, further analysis is essential to develop effective mitigation strategies and control measures based on the severity of pipeline damage caused by dropped anchors and other external factors [10].

The objective of this study is to assess the risk levels associated with anchor drop impacts on subsea pipelines, evaluate the potential hazards affecting the Natuna subsea pipeline route, and determine the frequency of incidents along with their associated consequences.

2. METHOD

The subsea pipeline analyzed in this study has a diameter of 16 inches, is constructed from API 5L X65 PSL 2 Q)/MO/NO material with a yield strength of 450 MPa, and consists of pipeline joints measuring 12.1 meters in length, located in the Natuna Sea. The risk assessment considers vessel traffic data in the vicinity of the gas pipeline, with a specific focus on large-capacity vessels, such as bulk carriers, as they are anticipated to pose higher risks. The anchor used in the analysis is assumed to be a stockless anchor, with its specifications derived from the BKI 2009 Volume 2 guidelines. The vessels and anchors included in the risk assessment are detailed in Table 1.

Tabel 1. Vessel and Anchor Data

Vessel Type			Anchor		
	Weight (Kg)	Volume (m3)	Length B (m)	Breadth C (m)	Project area (m)
Chemical thanker	480	0,06	1,000	0,276	0,46
Tongkang geladak	1290	0,17	1,380	0,456	0,87
Hopper Dragdger	1500	0,19	1,450	0,460	0,96
LNG Tanker -20.000	3000	0,38	1,708	0,630	1,53
LNG Tanker -150.000	907	1,28	2,253	0,660	1,53
Bulk Carrier B	16500	2,10	2,820	1,210	8,6
Bulk carrier A	6450	0,82	1,820	0,660	1,8

The consequence assessment in this study is based on the degree of pipeline deformation, which is measured as the ratio of dent depth to pipeline diameter. This evaluation follows the guidelines outlined in DNV-RP-F107.

3. RESULT AND DISCUSSION

Pipeline Energy Absorption Capacity

At a dent/diameter ratio of 5%, the energy that the pipeline can withstand is calculated as follows:

$$m_P = \frac{1}{4} \cdot \sigma_y \cdot t^2$$

$$mp = \tfrac{1}{4}.\, 450000000\ N/m^2.(0{,}0095\ m)^2$$

$$mp = 10153{,}1\ N$$

The energy absorbed by the pipeline is determined using:

$$E = 16.\left(\frac{2\Pi}{9}\right)^{\frac{1}{2}}.\, mp\, .\left(\frac{D}{t}\right)^{\frac{1}{2}}.\, D\, .\left(\frac{\delta}{D}\right)^{\frac{3}{2}}$$

$$E = (16.\left(\tfrac{2.3{,}14}{9}\right)^{\frac{1}{2}}.\, 10153{,}1\, .\left(\tfrac{0{,}4064}{0{,}005}\right)^{\frac{1}{2}}.\, 0{,}4064\, .\left(\tfrac{5\%}{0{,}4064}\right)^{\frac{3}{2}})/1000$$

$$E = 4{,}03\ KJ$$

The energy absorption capacity of the pipeline at different dent/diameter levels is shown in Table 2.

Tabel 2. Energy Absorption Capacity

Dent/Diameter	**Energy (KJ)**

5%	4,03
10%	10,17
15%	18,68
20%	28,77

The pipeline is coated with a protective concrete layer; therefore, the energy absorbed by the concrete layer must be considered. The energy absorption capacity of the concrete layer is calculated as follows:

$$E_k = Y \cdot b \cdot \frac{4}{3} \cdot \sqrt{D \cdot xo^3}$$

$$E_k = (105 \cdot 10^6 \cdot 0{,}25 \cdot \tfrac{4}{3} \cdot \sqrt{0{,}4064 \cdot (0{,}095)^3}\ )/1000$$

$$E_k = 653{,}33$$

The energy absorbed by the concrete layer is added to the energy that the pipe can withstand at each dent-to-diameter ratio, resulting in the consequence ranking presented in Table 3. The consequence ranking illustrates the amount of energy required to cause damage to the pipe at each dent-to-diameter level.

Tabel 3. Consequence Ranking

Rank	Dent/Diameter	Energy (KJ)
1	< 5%	655,36
2	5% - 10%	655,36 – 664,74
3	10% - 15%	664,74 – 674,29
4	15% - 20%	674,29 – 685,60
5	>20%	685,60

Consequences of Pipeline Damage Due to Dropped Anchors

The steps for calculating the anchor impact energy on the pipeline, also referred to as effective kinetic energy, have been outlined in the theoretical background. These steps are as follows:

1. Determining Terminal Energy

The drag coefficient of the anchor under consideration is 1,2, based on the DNV-RP-F107 standard.

$$E_T = \frac{m \cdot 9}{C_D \cdot A} \cdot (\frac{m}{\rho_{water}} - v)$$

$$E_T = \frac{480\ kg \cdot 9{,}81 m/s^2}{1{,}2 \cdot 0{,}46\ m^2} \cdot (\frac{480\ kg}{1025\, \frac{kg}{m^3}} - 0{,}06\ m^3)$$

$$E_T = 3482{,}91$$

2. Determining Terminal Velocity

$$E_T = \frac{1}{2} \cdot m \cdot v_T^2$$

$$V_T^2 = \frac{2 \cdot 3482{,}91}{480}$$

$$V_T = 3{,}81\ m/s$$

3. Determining Added Mass

The added mass coefficient is obtained from DNV-RP-F107, with a value of 0,7 for the anchor in this study.

$$m_a = \rho_{water \cdot Ca} \cdot v$$

$$m_a = 1025\frac{kg}{m^3} \cdot 1{,}02 \cdot 0{,}06m^3$$

$$m_a = 62{,}73$$

4. Determining Effective Kinetic Energy

$$E_E = E_T + E_A = \frac{1}{2}(m + m_a) \cdot V_T^2$$

$$E_E = \left(\tfrac{1}{2}(480\ kg + 62{,}73\ kg) \cdot 3,81^2\right) / \ 1000$$

$$E_E = 3{,}94\ KJ$$

The calculation results indicate that the anchor impact energy on the pipeline is 3.94 kJ. The consequence level of pipeline deformation due to anchor impact is classified as Level 1 in the consequence ranking, corresponding to a dent-to-diameter ratio of less than 5%.

Risk Assessment of Dropped Anchor Impact

In this study, the risk level associated with anchor drop impact on the subsea pipeline is assessed using a risk matrix in accordance with DNV-RP-F107. Based on the analysis of frequency and consequence, the frequency and consequence rankings for the pipeline due to anchor impact are determined as shown in Table 4.

Tabel 4. Frequency and Consequence Ranking for Dropped Anchor Pipeline Impact

Hazard	Anchor Weight (kg)	Code	Frequency Level	Consequence Level
Dropped anchor	450	57M	1	1
	1290	58M	1	1
	1500	59M	1	1
	3000	60M	1	1
	6450	61M	1	1
	9072	62M	1	1
	16500	63M	1	1

Tabel 5. Risk Matrix for Dropped Anchor Incidents

		Consequence Ranking				
		1	2	3	4	5
		Minor Damage	Moderate Damage Leakage Anticipated	Major Damage. Leakage Anticipated	Major Damage leakage end rupture anticipated	Rupture
		< 5%	5% - 10%	10% - 15%	15% - 20%	>20%
5	High	🟨	🟥	🟥	🟥	🟥
4	Relatively High	🟩	🟨	🟥	🟥	🟥
3	Medium	🟩	🟩	🟨	🟥	🟥
2	Relatively low	🟩	🟩	🟩	🟨	🟥
1	Low	🟩 E_E	🟩	🟩	🟨	🟨

Based on the analysis of the risk matrix, it can be concluded that the risk of pipeline damage caused by dropped anchors under various scenarios remains within an acceptable zone and falls under the ALARP (As Low as Reasonably Practicable) category. This implies that although the potential risk cannot be entirely eliminated, the level of risk remains within acceptable limits with the implementation of reasonable, practical, and effective control and mitigation measures.

The ALARP category indicates that the risk has been managed to the lowest feasible level, where any additional efforts to further reduce the risk would not provide benefits proportional to the resources expended. In this context, any necessary additional control measures should strike a balance between benefits and costs, while also considering the impact on operational safety and environmental sustainability. With the appropriate control measures in place, the risk associated with dropped anchors is still considered manageable and controllable without requiring significant additional intervention, provided that the existing control measures are consistently adhered to.

4. CONCLUSION

This study involved data collection on vessels passing through the subsea pipeline area in the Natuna Sea to monitor ship activities and mitigate potential risks of pipeline damage. The risk level associated with anchor drops was found to be within an acceptable range and classified under the ALARP (As Low As Reasonably Practicable) principle. A risk assessment was conducted using data from six vessels operating outside the pipeline area. Among them, two vessels exhibited an increased probability of anchor drops, ranging between >5% and <10%. While this level of risk remains within an acceptable threshold, it necessitates more rigorous mitigation measures, including enhanced vessel traffic monitoring, the establishment of anchor exclusion zones, improved pipeline resilience against external impacts, and the implementation of additional control measures to ensure that the risk remains within a manageable and reasonable limit.

Looking ahead, potential changes in vessel traffic patterns—such as increased maritime activities due to shipping growth, offshore development, or fishing operations—may elevate the risk to subsea infrastructure. These evolving dynamics highlight the need for continued monitoring and more comprehensive research that can provide accurate, real-time data and predictive insights. Such efforts will be essential to develop more effective and adaptive mitigation strategies, ensuring the long-term safety and integrity of the pipeline system amid future uncertainties.

REFERENCES

[1] A. Rahman, R. Richards, P. Dargusch, and D. Wadley, "Pathways to reduce Indonesia's dependence on oil and achieve longer-term decarbonization," *Renewable Energy*, vol. 202, pp. 1305-1323, 2023/01/01/ 2023, doi: https://doi.org/10.1016/j.renene.2022.11.051.

[2] M. Randolph and S. Gourvenec, *Offshore Geotechnical Engineering*, 1st ed. ed. CRC Press, 2011.

[3] F. Hou, Y. Chen, Y. Yan, R. Liu, Y. Liu, and R. Zhong, "Structural response and damage assessment method for subsea pipe-in-pipe subjected to anchor impact," *Marine Structures*, vol. 99, p. 103714, 2025.

[4] F. Jiang and S. Dong, "Two-level quantitative risk analysis of submarine pipelines from dropped objects considering pipe–soil interaction," *Ocean Engineering*, vol. 257, p. 111620, 2022.

[5] R. Selker, P. Liu, D. Karras, R. Bijker, and O. Aktan, "Impact of dropped objects and anchor dragging on pipeline integrity," in *ISOPE International Ocean and Polar Engineering Conference*, 2018: ISOPE, pp. ISOPE-I-18-537.

[6] A. Mustafina, "Anchor damage assessment of subsea pipelines-optimization of design methodology," University of Stavanger, Norway, 2015.

[7] S. A. Murtopo and L. Chimayati, "Kajian Pengelolaan Kecelakaan Kerja Industri Minyak dan Gas Lepas Pantai (Offshore) dengan Metode Failure Mode Effect and Analysis (FMEA)," *UEEJ-Unbara Environmental Engineering Journal2*, vol. 3, no. 02, 2023.

[8] A. D. Endijanto, "Analisis Risiko Kecelakaan Kerja pada Progressive Pigging Pipa Bawah Laut 12" MOL LCOM-NGLB," Institut Teknologi Sepuluh Nopember, 2023.

[9] V. A. Tanujaya, R. L. Tawekal, and J. R. Tawekal, "DESAIN DAN ANALISIS RISIKO PIPA BAWAH LAUT DI PERAIRAN LAUT MADURA BERDASARKAN STANDAR DNVGL RP-F107."

[10] A. P. D. Utomo, D. V. Siregar, E. F. Manurung, J. H. M. Sitinjak, and W. Hidayat, "Analisis Risiko dan Mitigasi Pencemaran Laut Akibat Kecelakaan Kapal di Alur Pelayaran," *Jurnal Ilmiah Manajemen, Ekonomi, & Akuntansi (MEA)*, vol. 8, no. 2, pp. 1855-1873, 2024.

[11] D. R. Aldara, R. S. DewI, and A. M. Mulananda, "Analisa Kerusakan Pipa Bawah Laut Akibat dari Kejatuhan Jangkar," *Techno Bahari*, vol. 9, no. 2, 2022.