Risk assessment of ships collision during installation of anode protection on subsea gas pipeline located in Surabaya West Access Channel

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Abstract. Subsea pipeline is one of alternatives to transport gas from offshore platform to onshore production facility. In Surabaya West Access Channel (APBS), there are some subsea gas pipelines lay on seabed. Maintenance of subsea pipeline should be carried out to ensure the sustainability of gas delivery, such as replacement of Sacrificial Anode Cathodic Protection. Since the replacement activity includes operation of Diving Support Vessel (DSV) along the subsea pipeline, it could potentially induce ship collision between DSV with other ships passing through the channel. This paper carried out a risk assessment of ship collision during replacement of anodes of subsea gas pipeline in APBS. The frequency of ship collision is analyzed by using Computerized Risk Assessment of Shipping Hazards (CRASH) and Traffic Based Models. The consequence is analyzed using Finite Element Method (FEM) which results the impact of collision on the hull of ship. Deformation of hull requires cost of repair which further becomes the outcome of consequences analysis. The risk is represented in the risk matrix which adopted from the Australian Standard Guidelines. The result shows that frequency of collision is 0.1342 per year while the consequences analysis results US$ 2,160,077 which required for repair. The risk representation shows that the anodes replacement has an extreme risk level based on the Australian Standard Guidelines. Further preventive measures are required to reduce the level of risk to be medium or low level of risk.

1. Introduction
The operation of the upstream oil and gas industry has a strategic contribution for the nation and state. The domestic energy supply continues to be maintained so as to increase energy security and provide a chain effect on the national industry and economy. Indonesia has some national oil and gas company that have some field productions over some locations in Indonesia. There is some field exploration located in shore and offshore. Subsea pipeline is required when offshore exploration facility is operated to supply the oil and gas as the result of production to the onshore gas processing facility. Jawa Timur is one of locations in Indonesia that have quite many explored oil and gas field. Some subsea gas pipeline lies on the seabed transporting the products from offshore production facilities. We can find them along the West Access Channel of Surabaya (APBS). Safety of subsea pipeline is one concern that emerge since the APBS is one of the busy channel which thousands of ships sail through the channel monthly. This channel is very busy since this is only the way for ship to visit Tanjung Perak Port Located in Surabaya, Jawa Timur. This port is the second biggest port in Indonesia after Tanjung Priok Port in Jakarta.
Pipeline is a facility as a means to flow a fluid such as oil, gas or water in large quantities and a long distance through the sea or certain regions. Pipeline needs to be maintained regularly in order to maintain the pipeline performance. Pipeline lies through subsea terrain which has very diverse contour, starting from the deep sea, lowlands, valleys, and in the soil. In its operation, there could be fatigue, corrosion, or cracks and disconnections. Such problems should be managed to avoid pipeline deterioration and failure which shorten its lifetime. Corrosion is a problem that must be carefully considered because it causes a consequence which shorten and worsen the quality of the pipes [1]. Pipeline wall thinning and leakage are the result that caused by corrosion and likely contribute to explosion if the hydrocarbon leakage ignited by source of fire. An effort to overcome corrosion of subsea pipeline uses Sacrificial Anode Cathodic Protection. The anode is sacrificed based on galvanic principle. The subsea pipeline is protected by using other metals which more anodic (more negative) than the metal that wants to be protected [2]. The protected metal will be the cathode and will not be corroded since the anode will be sacrificed during its period of lifetime.

One of subsea gas pipeline located in APBS transfers hydrocarbon from a site in north side of Madura Island to onshore facilities in Gresik. This study will focus on this subsea facility. Maintenance of this subsea pipeline is necessary to be carried out in a certain period of time, especially maintenance for replacement of the sacrificial anode on the pipeline [3]. During replacement of anode, some requirement is needed such as divers, new anodes to be installed, and special vessels that able to work without anchoring during installation of anode. Anchoring increases risk for subsea pipeline in event of anchor drop and drag which likely lead to pipeline failure. The replacement of anode utilizes Dive Support Vessel (DSV) which is operated along the subsea pipeline. During anode installation, DSV will stay in location which near the shipping line in APBS. The DSV activity during some period of time near the shipping channel increases the probability of ship collision.

The purpose of this paper is to analyse the probability and consequence of collision between DSV during anode installation and ship passing the APBS. The output of this study is important since the frequency of collision in APBS is quite high. The subsea pipeline operator could consider the probability and consequence of collision if such method of anode replacement is carried out. In this paper, the frequency of collision is analysed by using Computerized Risk Assessment of Shipping Hazards (CRASH) and Traffic Based Model while the consequence is analysed by using finite element method simulation. By obtaining the frequency and consequence of collision, risk could be determined. This paper uses Australia Standard Guidelines risk matrix [4]. A mitigation is then could be proposed if the risk level is unacceptable while mitigation is not required when the risk level is acceptable.

2. Overview of Surabaya West Access Channel (SWAC))

Surabaya West Access Channel (SWAC) is located between Java Island and Madura Island. This channel is very busy since it becomes the only one channel that is used by ships approaching Port of

![Figure 1. Location of subsea gas pipeline near the shipping channel in APBS](image)
Table 1. Number of ship passing SWAC [5]

| Year | Number of ship |
|------|----------------|
| 2008 | 20951          |
| 2009 | 20834          |
| 2010 | 19847          |
| 2011 | 19742          |
| 2012 | 20624          |
| 2013 | 24093          |
| 2014 | 19895          |
| 2015 | 19115          |
| 2016 | 23352          |
| 2017 | 26901          |

Tanjung Perak from the Java Sea. This shipping channel wide is 150 – 200 m, with channel depth is up to -16 m. Port of Tanjung Perak is the second biggest port in Indonesia. It is in Jawa Timur provinces and it operates container terminal, bulk, passenger and general cargo. This makes the channel is busy with ship traffic.

Table 1 shows the number of ship passing SWAC each year. The number of ships seems increase gradually from 2008 until 2017 even though sometimes fluctuates [5]. Based on this data, the number of ship is probably increase since the government concern on the economic development that will impact on the ship utilization for trading.

Based on the history, ship collision in SWAC is quite high. There are total 107 event of collisions during 2012 until 2017 [6]. Ship fire, sinking, contact and grounding are the type of collision that appear, while the fire, sinking and contact becomes the most frequently happened. Table 2 shows the number of yearly ship collision as well as the fatality that appear after investigation. During this period, there are 931 cases of fatalities and 631 injury caused by the ship collision in SWAC. Since contact is one of the most frequent collision event in SWAC, the replacement of anode which utilizes Dive Support Vessel should be more considered. However, the long term appearance of DSV in the location during the anode replacement would increase the probability of ship collision which involve another ship in the shipping channel which may induce severe consequences.

The channel which is quite narrow with the 200 m cross sectional wide. This is also one factor that should be considered since the narrower the shipping channel, the collision will be more likely to be happened. Additionally, the factor that contribute to the probability of collision during anode replacement is the scenario of DSV operation. The scenario of DSV operation causes the duration of her operation in the shipping channel, while the longer the appearance of DSV in the channel, the more likely the collision to be occurred.

Table 2. Number of ship collision in SWAC [6]

| Year | Number of collision | Sinking | Types of Collision | Fatalities |
|------|---------------------|---------|--------------------|------------|
|      |                     |         | Fire | Contact | Grounding | Loss of life | Injury |
| 2012 | 4                   | 0       | 2    | 2       | 0         | 13          | 10    |
| 2013 | 6                   | 2       | 2    | 2       | 0         | 65          | 9     |
| 2014 | 7                   | 2       | 3    | 2       | 0         | 22          | 4     |
| 2015 | 11                  | 3       | 4    | 3       | 1         | 85          | 2     |
| 2016 | 18                  | 6       | 4    | 3       | 3         | 46          | 18    |
| 2017 | 34                  | 6       | 14   | 6       | 6         | 42          | 2     |
| Total| 107                 | 29      | 40   | 24      | 10        | 931         | 631   |
3. Risk assessment

Risk assessment is carried out by determining the frequency and consequence of ship collision during installation and replacement of anode protection into the subsea gas pipeline which the location as shown in Figure 1. This section will discuss about the scenario of anode installation.

3.1. Scenario of anode replacement on subsea pipeline

DSV is used for mobilization and process of installation of anode. During conducting installation, DSV is operated in sea water above the location of subsea pipeline. She is located in that position until the anode installation is completed. The installation of anode is carried out along the 16 inches diameter of subsea pipeline which lies from KP (Kilo meter pipe) 0 to KP 64. This subsea pipeline covers more than 1453 points where anode needs to be replaced. Distance between anode is 44 m. The location and number of anode which need to be installed can be seen in Table 3. This paper considers the pipeline starting from KP 0 to KP 64. KP 0 is the location of pipeline starting point in the offshore production facilities. However, KP 29 - KP 64 is closer to the SWAC than the KP 0 - KP 29.

| Pipe Section | Distance between anode (m) | Number of Anode |
|--------------|---------------------------|-----------------|
| KP 0 - KP 9,5 | 44                        | 216             |
| KP 9,5 - KP 29 | 44                        | 443             |
| KP 29 - KP 64 | 44                        | 795             |
| KP 64 - KP 66,046 | 44                    | 47              |

The frequency of collisions that occur during the anode replacement process is calculated based on the duration of DSV activity around SWAC. The DSV that is used for anode installation can be seen in Figure 2 bellow. The information of the DSV is obtained from the operator of oil and gas company that owned the subsea gas pipeline which is analyzed. The vessel is equipped with dynamic positioning system type 2 and the dimension are Length = 65 m, Breadth = 15,8 m and Draft = 4,8 m. Based on the results of research conducted by Jim Britton and Dick Baxter [7], the duration of replacing this anode takes 4 to 18 hours per point of the anode location. The duration of the replacement process depends on some factors, including type of vessel, weather condition (wind, waves and sea current), the sea water depth where the pipe is located, type of pipeline laying on seabed i.e. exposed or burial under the seabed.

The following Table 4 summarizes the estimated duration of anode replacement for each of the anodic location points. The installation process generally comprises of 5 activities. They are expose pipe, location set up, pipeline preparation, anode preparation and installation. The longest duration is for pipeline preparation which is done by preparing the pipeline before installation, such as cleaning the outer layer of the pipe from objects attached to it such as soil, rocks or coral. It spends 4 hours while the total duration for installation and replacement of anode for one location is 9 hours. Based on this information, DSV should be standby in location at least during this activity. Further, the duration for DSV to be located near the SWAC during anode installation is used for frequency analysis of ship collision.
3.2. Frequency analysis

Before calculating the frequency of collisions that occurs on DSV, we should determine the possible types of collisions that may occur. The type of collision can be head on, crossing, overtaking and drifting collision. The type of collision that may occur is determined based on the location of the pipe whether it is inside or outside the shipping channel. After observing the map of the location of the pipeline, it can be determined that the entire subsea pipeline laying from KP 0 to KP 64 is outside the shipping channel. Additionally, the collision that may occur is the collision of a ship due to a drifting collision. This type of collision is possible since the DSV is located outside the shipping channel and in a stationary condition in most of anode replacing period. The collision type that may occur is not relevant for the type of impact such as head-on, crossing and overtaking. These three types of collisions can occur only if the two objects are mutually moving and not just one relative to stationary object. For this reason, only the type of drifting collision is most suitable in this case.

In this paper, the frequency of collision is carried out by using two methods. They are CRASH Model and Traffic Based Model method. The case of drifting collision in this paper is calculated for four case drifting angle variations, i.e. 10°, 30°, 45°, and 60°. Figure 3 shows the variation of calculations based on the degree of drifting angle. We can see that the dark blue colour in picture on the left is a tanker vessel while the light blue on the right is a DSV vessel that carries anode that will be installed on the subsea pipeline. The red line is the projection of the ship's drifting to form a certain angle. In this paper, tanker vessel is chosen with the biggest size that is recorded to pass the SWAC previously to have a clear view on how the consequences would be. The ships analysed in this paper is all the ships that pass SWAC which going to or from Gresik and Tanjung Perak port Surabaya. The number of vessels that have passed the APBS in the past 10 years (2008 - 2017) is shown in Table 1. By using regression method, estimation of the number of vessels passing through the APBS in 2018, 2019 and 2020 is obtained as 23917, 24350 and 24783 respectively. Based on this data, in 2019, the number of vessels passing through the SWAC per hour is 2.73. As explained earlier, the working time of anode installation needs 9 hours. The number of ships passing for 9 hours is 26 ships.
3.2.1. CRASH model
The type of collision that might occur between ships passing the SAWC and DSV is drifting collision. Drifting collision is a condition where the ship is dragged by force of current, waves, and wind that blows towards an object until the ship collides with the object [8]. This collision generally starts with an engine failure in operation which causes the engine shutdown. This happens when the following conditions happened:
- Ship propulsion system failure
- Ship crew failed to repair onboard
- The wind makes the ship deviate from shipping channel
- The ship drifting could not be avoided causing collision with other object/vessel

The frequency of collision can be calculated by using CRASH Method as following equation:

\[ F_{CD} = N_b \times P_B \times P_W \times \frac{D}{BL} \]

Where:
- \( F_{CD} \) = frequency of collision due to drifting (per year)
- \( N_b \) = number of ships passing through the shipping channel (ship / year)
- \( P_B \) = probability of failure
- \( P_W \) = probability of wind blowing
- \( D \) = collision Diameter
- \( BL \) = the length of a straight line towards the wind

3.2.2. Traffic based model
Traffic Based Models is an approach to calculate the collision frequency that is adjusted to technical standards, environmental conditions and density of ship traffic in certain waters[9]. This method can be used to estimate the frequency of head-on, grounding and also intersections in a specific area as in Figure 3 below. Drifting occurs when a ship fails to navigate and is carried away by the current, allowing an accident to happened. The modelling of ship accidents due to drifting is shown in the Figure 4 below, where the ship sailing in the shipping lane with a \( W \) width and the relative distance of the fairway is \( D \). The probability of event of drifting can be estimated using the following equation[9]:

\[ P_i \approx 1 - \frac{2}{\pi} \cdot \frac{W}{D} \]

Where:
- \( P_i \) = conditional probability of drifting
\[ W = \text{average shipping line width (m)} \]
\[ D/2 = \text{distance of ship with object at a certain angle (m)} \]
\[ D = \text{the length of the fairway (m)} \]

**Figure 4.** Modelling of Drifting Collision using Traffic Based Model[9]

The probability of vessel losing control due to navigation failure:

\[ P_e = \frac{P_a}{P_i} \]

Where:
\[ P_a = \text{accident probability} \]

### 3.3. Consequence analysis

Consequence analysis of drifting collision in this paper is carried out by taking into account a collision of DSV with other ship that has the biggest dimension that pass the SWAC. The purpose choosing this ship is for giving clear interpretation on how the consequences would be, when drifting collision occurs on one of the biggest dimension of ship. Based on data from port authority of Tanjung Perak Surabaya in 2018, the biggest vessel that have passed SWAC was a tankers named MT Sanga Sanga which entered on April 10, 2018. The analysis was conducted to determine the structure of damage to the ship's body using a 3D simulation. The simulation of drifting collision analyses the impact on the hull of ship which is interpreted as equivalent Stress, directional deformation, and total deformation.

Previous study determined that the breakdown of engine causes the ship starts to drifting at certain angles with a drifting speed of 3 knots [10]. In order to obtain clearer view on the effect of drifting speed on the consequences, this study carried out collision modelling with some speed variations including 3 knots, 5 knots, 9.5 knots, and 10.2 knots. The impact on the hull of ship will be converted into cost as a result of consequences analysis. The cost that should be paid by hull repair is comprised of cost for new hull plate, re-plating work services, fuel loss and ship charter services. After gaining the result of frequency and consequences analysis, risk is interpreted in a risk matrix. This paper uses Australia Standard Guidelines (AN/NZ 4360:1999) [4] to interpret the result of frequency and consequence analysis in order to know the level of risk.

### 4. Result and discussion

Method of frequency and consequence analysis have been discussed in previous chapter with all the scenario that is considered during the replacement and installation of anode on the subsea gas pipeline in SWAC using DSV. Firstly, the frequency analysis has been done by using CRASH model and Traffic Based Model. Based on the results of calculations, the two models show an agreement about the frequency of drifting collision during the subsea pipeline anode replacement process. The collision frequency of drifting collision is less than 1/year in all scenario. However, it can be seen that the result of frequency of the drifting collision with CRASH Model is bigger than Traffic Based Model. Table 5 shows the comparison of result for both models. Basically, these two models are relatively difficult to compare because each model has different assumptions and causes. In CRASH model, the ship experiences drifting due to engine failure that cannot be overcome in a certain time, while the Traffic
Based Model, the drifting is caused by loss of navigational control. The CRASH Model also takes into account the breakdown per hour and wind blowing which causes the ship to deviate from the shipping channel and collide with DSV.

The result of calculation shows that the annual frequency is less than 1 for all the collision scenario. It shows that all comparison of frequency calculation has relatively similar result. However, we can see in Table 5 that there is one scenario that has the biggest difference for both model, i.e. scenario 60° while another scenario has quite similar result. These result is in frequency level 2 for scenario drifting angle 10°, 30°, and 45°, while drifting angle 60° results the frequency level 1. The frequency level is based on the Australia Standard Guidelines for risk matrix.

| Table 5. Frequency of drifting collision during anode replacement on subsea gas pipeline |
|----------------------------------------------------------------------------------------|
| Frequency of drifting collision per year                                               |
| 10°  | 30°  | 45°  | 60°  |
| CRASH | 0.0673 | 0.0767 | 0.0942 | 0.1342 |
| TBM   | 0.0767 | 0.0762 | 0.0755 | 0.0747 |

The consequence analysis is carried out by simulation which is done using Finite Element Method. The drifting collision involve DSV and tanker vessel that has been described above. As discussed previously, the simulation results equivalent stress, directional deformation and total deformation. Figure 5 shows result for scenario drifting speed 10.2 knots. Similar simulation is carried out for other scenario, i.e. 3, 5, and 9.5 knots. Collision causes damage on the ship hull for both vessels. The simulation results an estimation on how wide the damage could be happened. We can see the result of simulation in consequence in risk matrix. Based on the Australia Standard Guidelines (AN/NZ 4360:1999) risk matrix, the result of consequence analysis is in level 4 for all scenarios.

Table 6. This table shows the damaged area based on scenario of simulation which based on the drifting speed. It is obviously can be seen that as high the speed of ship, the damaged area of ship hull will be wider. The simulation of collision on scenario 3, 5, 9.5 and 10.2 knots results area damage of 119.7, 135.9, 228.6 and 287.1 m² respectively.

Based on the area damage that has been resulted, the consequences analysis will be further analysed to determine the cost that should be payed to repair the damage on ship hull. The value of cost that is needed is depend on the area which need to be repaired. Since the wider the damage area causes more expensive of repair treatment, the highest speed could induce the highest cost that is
needed for repair. The result of the cost needed are $2,150,157.14, $2,152,991.43, $2,157,242.86 and $2,160,077.14 respectively when we apply speed 3, 5, 9.5 and 10.2 respectively such as shown in Table 7. These results are used to interpret the level of consequence in risk matrix. Based on the Australia Standard Guidelines (AN/NZ 4360:1999) risk matrix, the result of consequence analysis is in level 4 for all scenarios.

Table 6. Total area of ship hull that need to be repaired

| Speed (knots) | Total of cells | Area / Cells (m²) | Total Area (m²) |
|--------------|---------------|-------------------|-----------------|
| 3            | 133           | 0.9               | 119.7           |
| 5            | 151           | 0.9               | 135.9           |
| 9.5          | 254           | 0.9               | 228.6           |
| 10.2         | 319           | 0.9               | 287.1           |

Table 7. Result of consequences analysis

| No. | Speed (knots) | Total cost required |
|-----|---------------|---------------------|
| 1   | 3             | $2,150,157.14       |
| 2   | 5             | $2,152,991.43       |
| 3   | 9.5           | $2,157,242.86       |
| 4   | 10.2          | $2,160,077.14       |

Figure 6. Risk interpretation of drifting collision during anode replacement

The result of frequency analysis which has 4 scenarios drifting angle (10°, 30°, 45° and 60°) and consequence analysis that has 4 scenarios of speed variation (3, 5, 9.5 and 10.2 knots) have been obtained. Risk level is determined based on these results. Risk representation is done by using Australia Standard Guidelines (AN/NZ 4360:1999) which is shown in Figure 6 above. This figure that there are two type of risk interpretation shown in figure. The blue colour interprets the risk level for
frequency of drifting angle scenario 10°, 30°, and 45° with all scenario of speed variation for consequence analysis. The green colour is the risk representation for frequency of drifting angle scenario 60° with all scenario of speed variation for consequence analysis. It can be obviously seen that all the risk representation is in extreme (E) based on the risk matrix of Australia Standard Guidelines.

Risk of drifting collision during anode replacement in subsea gas pipeline is at extreme level, mainly caused by the consequence level which is in level 4 and frequency in level 1 and 2. Mitigation should be considered to reduce the risk level for this activity. Mitigation can be aimed to reduce the frequency or consequence. Some effort that can be applied for mitigation such as informing the activity of DSV to be announced by port authority to all voyage in SWAC, employ tugboat/pilot boat around DSV during anode replacement, use any navigation aids during activity such as buoy etc. This paper does not discuss in detail about mitigation that should be taken and how it will change the risk level. Further discussion and study can be carried out in near future to complete this study.

5. Conclusion
SWAC is a shipping channel which has a busy ship traffic and contain some subsea gas pipeline which passed on the seabed of this seawater. Subsea gas pipeline needs maintenance for replacement of its anode to prevent from corrosion. This paper has analysed the risk of drifting collision of DSV and other ship during anode replacement of subsea pipeline in SWAC. Frequency analysis has been carried out using CRASH model and Traffic Based Model for four type of drifting angle scenario, while consequence analysis was carried out using Finite Element Method with four type of ship speed variation. Result of frequency and consequence analysis were plotted in Australia Standard Guidelines (AN/NZ 4360:1999) risk matrix to interprets the risk level of event of drifting collision during anode replacement on subsea gas pipeline in SWAC. All the scenario showed that risk representation is in extreme level. Further, this research would pursue more insight of mitigation in order to reduce the risk level.

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