Risk Assessment in Dropped and Drag Anchor in Offshore Pipeline Based on DNV RP F107 and DNV RP F111

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Abstract. This research conducts risk assessment towards the offshore pipeline against one of the potential hazards which can occur, namely the incident of dropped anddragged anchors. The method applied in this study involves assessment using the standard code DNV RP F107 and DNV RP F111. The main parameters involve in the study to generate the level of risk include the frequency of occurrence and the amount of energy from the dropped and dragged anchor. The output of the assessment is reflected in the risk matrix. Two types of pipelines were used, namely pipeline A with outer diameter of 150 mm wall thickness of12.5 mm, and pipeline B with outer diameter of 219 mm and wall thickness of 7.95 mm, are studied against two different anchors' weight. The weight of the anchor is 1,590 kg and 2,870 kg, respectively. The analysis towards the frequency of dropped and dragged anchor and the amount of energy from dropped and dragged anchored has been performed for both types of pipeline. This research showed that both pipelines possessed a medium risk level for dropped and dragged anchors. The recommendation for the risk mitigation plan would be to provide concrete coating with thickness of 50 mm and 60 mm for 1,590 kg anchor and to provide 80 mm concrete coating for 2,870 kg anchor, resulting in the decrease of risk level to lower risk category.

Keywords: Risk assessment, dropped and dragged anchor, pipeline, risk matrix, risk mitigation.

1 Introduction

The need for petroleum products is very high, many sectors of life need and utilize petroleum products such as the industries, household, transportation, and construction sectors, which in turn resulted in the availability of petroleum products that must be maintained in order to meet the needs. UU No. 22 of 2001 firmly emphasizes the priority of utilizing Indonesia's natural gas to meet domestic needs [1]. There are several processes involved in the utilization of

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petroleum products, which include exploration, production, transportation, refinery and marketing. Through all of these interconnected and consecutive processes, pretroleum product can be taken its benefits to fulfill the demand.
One of the most important process in producing petroleum products is transportation. Pipeline is one of the most important transportation components in oil and gas production activities, which has the function to transport production fluids (oil and gas) from one distribution point to the next distribution point, for example to transport crude oil from production platform tothe receiving facilities eithere onshore or offshore.
During the process of design and operation, offshore pipeline posseses risk due to damage or failure which could be caused by natural factors or human actions. According to PARLOC (Pipeline and Riser Loss of Containment) 2001, several most common causes of offshore pipeline damage include damage due to ship anchors passing over the waters around the pipeline (21%), corrosion (26%), ship collision (30%), hazards posed by nature (5%), poor maintenance management (1%), faults at operation (1%), and other causes [2].

Potential hazard towards pipeline can be categorized into two, namely natural factor and human actions. From natural factor category, corrosion and other disaster such as storm and earthquake have a great damage potential but less probability to occur. On the contrary, corrosion is the one with high probability to occur, with varies damage potential depending on the operating condition. From the human actions category, anchor dragging dan ship collision bith can have a high damage potential as well as probability to occur[3]. from this point of view, it is clear that dropped and dragged anchor has great risk that can yield to offshore pipeline damage. Due to this reason, the need for risk assessment due to the hazard potential which caused by dropped and dragged anchor is important. This research aimed to performa risk assessment due to the hazard potential which caused by dropped and dragged anchor is important.

2 Literature Review

2.1 Risk and Its Assessment

Risk is defined as a threat to life, property or financial gain due to a hazard that occurs [3]. In general, risk is associated with the possibility (probability) of the occurrence of events outside the expected [4]. Risk assessment is an analytical process to generate risk categories from potential hazards to specific objects that are used to make decisions in the form of risk reduction strategies. Risk analysis is the relationship between probability and consequence which can emerge as a result of the risk. There are three approach which can be performed in order to assess risk, namely: qualitative, semi-quantitative and quantitative risk assessment. Qualitative risk assessment is an approach which assess the risk using qualitative scoring, on the opposite, quantitaive approach assesses the risk by using numerical and mathematical model. In additionl, a semi-quantitative approach combines both the quantitative and aqualitaive approaches. Figure 1 depicts the ilustration of risk matrix which used to map the risk during risk analysis.

The area which categorize as not acceptable is defined as area possessing high marked with red color, which means that there is a possibility of high risk that can damage the pipeline to the point of if could not function or experience failure. ALARP (as low as reasonably practiceable area) is defined as area with medium risk marked with yellow color, which means that there is a possibility of acceptable risk yet need further effort to minimize loss. And lastly, acceptable area which defined as area with low risk marked with green color, which means the hazard potential in under acceptable criteria [5].

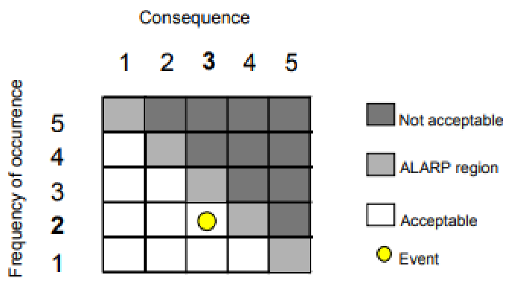

Fig. 1. Risk Matrix [5].

2.2 Potential Hazard

According to PARLOC (Pipeline and Riser Loss of Containment) 2001, several most common causes of offshore pipeline damage include damage due to ship anchors passing over the waters around the pipeline (21%), corrosion (26%), ship collision (30%), hazards posed by nature (5%), poor maintenance management (1%), faults at operation (1%), and other causes [2]. Figure 2 shows the distribution of the potential hazard which can cause offshore pipeline damage include damage. From this figure, it can be observed that the percentage of potential hazard due to human action, namely dropped and drag anchor, is considerably high (21%) after impact (30%) and corrosion.

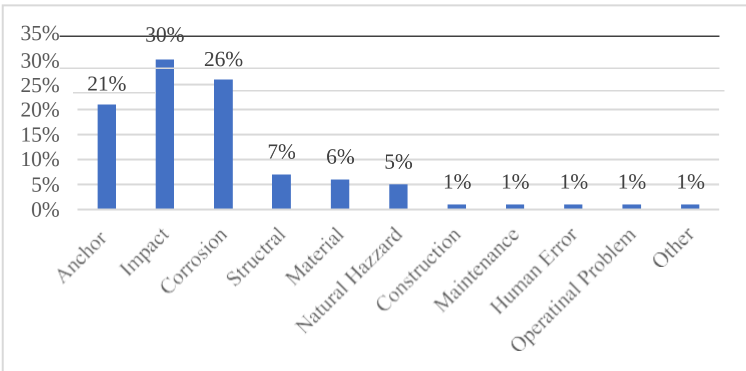

Fig. 2. Potential Hazards to Offshore Pipeline [2]

In circumstances such as dents or scratches on the subsea pipeline network, it can cause the pipeline to rupture and in the future it will result in a decrease of the durability of the pipeline so that it is not strong enough to withstand operational pressure loads [6]. The shape of a dented pipeline due to an object falling into the pipeline is ilustrated in Figure 3.

The impacts that occur due to the failure of the piping system are divided into two, namely direct impacts and indirect impacts. The direct impact of failure of the piping system is property/equipment damage, death/disease in humans, environmental damage, production loss (oil and gas), repair costs due to damage, and cleaning costs. Meanwhile, indirect impacts include litigation, breach of contract, consumer dissatisfaction, political reaction, loss of market share and fines/punishments from the government [7].

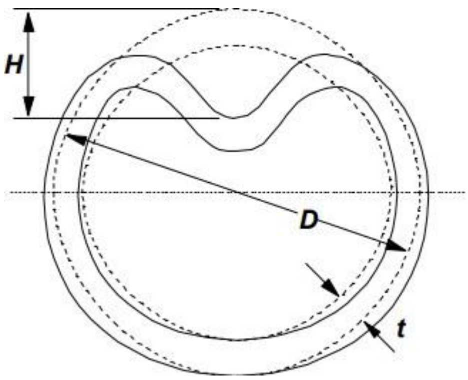

Fig. 3. Pipeline Dent Illustration [8]

2.3 Dropped and Dragged Anchor Analysis

The dropped anchor and dragged anchor analysis are carried out based on the reference DNV RP F107 and DNV RP F111. The frequency of dropped and dragged anchors will be categorized based on the categorization in Table 2 [5].

Table 2. Failure Frequency for Dropped and Dragged Anchor

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 summarised 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 once during lifetime	$> 10^{-2}$

Dent prediction model is shown in Figure 3. To calculate the energy impact absorbed by the dent, equation 1 from DNV RP F107 [9].

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

Where :

m_p : plastic moment capacity of the wall (N)
which given by

$$m_p = \frac{1}{4} \times SMYS \times t^2 \qquad (2)$$

In which:

δ	: dent depth (m)
t	: wall thickness (m)
D	: steel outer diameter (m)
SMYS	: specified minimum yield strength (Pa)

2.3.1 Analysis on Dropped Anchor

Dropped anchor occurs when the anchor is released and falls right on the pipeline, to determine the level of risk of dropped anchors, it is necessary to calculate impact energy analysis using an following equation based on DNV RP F107 [9].

a) Step 1: determine added mass (m_a) using equation 3

$$m_a = V_a \times \rho_w \qquad (3)$$

Where :

V_a : volume anchor (m^3)

ρ_w : water density (kg/m^3)

b) Step 2: determine Energy terminal (E_T) using equation 4

$$E_T = \frac{m_t \times g}{C_d \times A}\left(\frac{m_t}{\rho w} - Va\right) \qquad (4)$$

Where :

m_t : steel mass (kg)

g : gravity (m/s^2)

C_d : drag coefficient

A : projected area (m^2)

V_a : volume anchor (m^3)

ρ_w : water density (kg/m^3)

c) Step 3: determine Velocity terminal (v_t) using equation 5

$$v_t = \sqrt{\frac{2ET}{m_t}} \qquad (5)$$

Where :

E_T : energy terminal (J)

m_t : steel mass (kg)

d) Step 4: determine Impact energy (E_R) using equation 6

$$E_R = \frac{1}{2} \times (m_t + m_a) \times v_t^2 \qquad (6)$$

2.3.1 Analysis on Dragged Anchor

The analysis on the dragged anchor is divided into three analysis, namely impact energy, pull-over energy, and hooking energy. Impact energy is a load related to the transfer of kinetic energy from anchors or other objects to the pipeline, generally occurring in a very short time span, so that most of the energy transferred is then absorbed into local deformation. Pull-over analysis deals with the response when the anchor is pulled or forced through the pipe. Hooking is an event when the anchor moves and then gets stuck in the pipe. In this context, hooking occurs with the end of the anchor caught under the pipe, forced to stop, then back off, and freeing the anchor [10].

a) Impact Energy Analysis

Step 1: Determining steel mass impact energy (E_s)

$$E_s = R_{fs} \times \frac{1}{2} \times m_t (Ch \times v)^2 \quad (7)$$

Where :

R_{fs}	: reduction factor
m_t	: steel mass (kg)
C_h	: impact velocity coefficient
v	: effective impact velocity (m/s)

Step 2: Determining Hydrodynamic energy (E_a)

$$E_a = \frac{1}{2} \times m_a \times (C_h \times v)^2 \quad (8)$$

Where :

m_a	: hydrodynamic added mass (kg)
C_h	: impact velocity coefficient
v	: effective impact velocity (m/s)

The impact energy now can be determined as the summation of steel mass impact energy and hydrodynamic energy.

b) Pull-over Energy

Step 1: Determining dimensionless height (Ħ)

$$Ħ = \frac{Hsp + OD/2 + 0,2}{B} \quad (9)$$

Where :

H_{sp}	: span height (m)
OD	: outer diameter (m)
B	: Half height of anchor (m)

Step 2: Determining empirical force coefficient (Cf)

$$Cf = 8 \times (1 - e^{-0,8Ħ}) \quad (10)$$

Where :

Ħ : Dimensionless Height

Step 3: Determining pull-over load duration (Tp)

$$T_p = CT \times CF \times (\frac{mt}{kw})^{0,5} + \delta p/v \quad (11)$$

Where :

$$\delta p/v = \frac{CT \times CF \times (\frac{mt}{kw})^{0,5}}{10}$$

CT : coefficient pull-over duration

CF : coefficient geometry characteristic

m_t : steel mass (kg)

kw : warp line stiffness (N/m)

Step 4: Determining trawling velocity (v)

$$v = 2,8 \times C_h \quad (12)$$

Where :

C_h : coefficient for effect of span height on impact velocity

Step 5: Determining anchor displacement (s)

$$s = v \times Tp \quad (13)$$

Where :

v : trawling velocity (m/s)

Tp : pull-over load duration (s)

Step 6: Determining Maximum pull-over force (Fp)

$$Fp = CF \times v \times (mt \times kw)^{0,5} \quad (14)$$

Where :

CF : coefficient geometry characteristic

v : trawling velocity (m/s)

m_t : steel mass (kg)

kw : warp line stiffness (N/m)

Step 7: Determining pull-over energy (E_{po})

$$E_{po} = Fp \times s \quad (15)$$

Where :

Fp : maximum pull-over force (N)

s : anchor displacement (m)

c) Hooking Energy Analysis

Setp 1: Determining maximum lifting height (H_l)

$$H_l = 0{,}7B - 0{,}3OD \quad (16)$$

Where :

B : half height of anchor (m) is given by half value of anchor height

OD : outer diameter (m)

Setp 2: Determining Potential energy (Ep)

$$Ep = (m_t + m_a) \times g \times H_l \quad (17)$$

Step 3: Determining Kinetic energy (Ek)

$$Ek = \frac{1}{2} \times (mt + ma) \times v^2 \quad (18)$$

Step 4: Determining Hooking energy (E_H)

$$E_H = Ep + Ek \quad (19)$$

D. Mitigation

Mitigation is a series of actions to reduce the risk of harm, both through physical development and awareness and increase in the ability to face the threat of hazard [11]. Mitigation measures are needed to prevent unwanted losses or failures. The existence of mitigation is expected to minimize the impact of the potential hazards that exist so as to reduce the level of risk in the offshore pipeline. One of them is by applying a coating on the offshore pipeline in the form of concrete as a protection from the hazard of being dropped and dragged anchors. Based on DNV RP F107 to calculate the minimum concrete coating thickness using equation 18 [6].

$$E_H = Ep + Ek \quad (18)$$

$$E_k = Y \times b \times h \times X_0$$

$$X_0 = \frac{Ek}{Y \times b \times h}$$

Where :

Y : crushing strength (Pa)

b : breadth of impacting object (m)

h : the depth (m)

X_0 : penetration or concrete coating thickness (m)

3 Result and Discussion

To determine the risk assessment due to droped and dragged anchor on the offshore pipeline, calculation and analysis are performed based on DNV RP F107 and DNV RP F111. The process involved in the risk assessment include: data collection on the frequency of dragged and dropped anchor, calculation on frequency of dragged and dropped anchor.

3.1 Data Collection

In this research there are two type of pipelines used analysis, namely pipeline A and pipeline B. Pipeline A has material grade of bonded reinforced thermoplastic pipe (HDPE), with outer diameter of 150mm and wall thickness os 12.5 mm; on the other hand, pipeleine B has material grade of API 5L X52, outer thickness of 219 mm and wall thickness of 7.95mm. The anchor data used for analysis is taken from the heaviest from the heaviest mass of the anchors representing the company's operational and commercial vessels that passed near pipeline area. Two types of anchor, i.e. anchor with mass 1,590 kg and 2,870 kg, respectively, are selected.

3.2 Result

The data obtained are used to calculate the frequency of dropped and dragg anchor for both pipelines and anchor. The possible event of anchor dropped and draged on the pipeline is identified. Table 3 shows the frequency dropped and draged anchor. Table 4 shows the summary of the calculated energy released by both anchors on pipeline A, while Table 5 shows the calculated energy released by both anchors on pipeline B. The result as shown table below.

Table 3. Frequency of Dropped and Dragged Anchor

Cases	Frequency
1590 kg Anchor Against Pipeline A	$4{,}71667 \times 10^{-6}$
1590 kg Anchor Against Pipeline B	$4{,}83167\times10^{-6}$
2870 kg Anchor Against Pipeline A	$5{,}81667\times10^{-6}$
2870 kg Anchor Against Pipeline B	$5{,}93167\times10^{-6}$

Table 4. Dropped and Dragged Anchor Energy for Pipeline A

Parameter		Energy Released by Anchor (Joule)	
		1590 kg Anchor	2870 kg Anchor
Dropped Anchor		43,715.98	92,064.8
Dragged Anchor	Impact	8,589.4	15,504.14
	Pull-over	55,218.1	67,255.7
	Hooking	44,163.2	93,949.28

Table 5. Dropped and Dragged Anchor Energy for Pipeline B

Parameter		Energy Released by Anchor (Joule)	
		1590 kg Anchor	2870 kg Anchor
Dropped Anchor		43,715.98	92,064.8
Dragged Anchor	Impact	8,589.4	15,504.14
	Pull-over	68,000.77	83,268.57
	Hooking	43,149.36	92,119.28

From the dropped and dragged anchor energy result shown in the table above, the risk matrix can be constructed as shown in Figure 4,5,6, and 7. The symbol W represents the dropped anchor energy, X represents the impact energy, Y represents the pull-over energy, and Z represents the hooking energy.

RISK MATRIX							
Frekuensi	5	>10^-2					
	4	(10^-3) - (10^-2)					
	3	(10^-4) - (10^-3)					
	2	(10^-5) - (10^-4)					
	1	<10^-5					W,X,Y,Z
Low Risk			<0,083	0,083-0,235	0,235-0,433	0,433-0,667	>0,667
Medium Risk			1	2	3	4	5
High Risk			Konsekuensi (KJ)				

Fig. 4. Risk Matrix 1590 kg Anchor Against Pipeline A

RISK MATRIX							
Frekuensi	5	>10^-2					
	4	(10^-3) - (10^-2)					
	3	(10^-4) - (10^-3)					
	2	(10^-5) - (10^-4)					
	1	<10^-5					W,X,Y,Z
Low Risk			<0,977	0,977-2,764	2,764-5,077	5,078-7,818	>7,818
Medium Risk			1	2	3	4	5
High Risk			Konsekuensi (KJ)				

Fig. 5. Risk Matrix 1590 kg Anchor Against Pipeline B

RISK MATRIX							
Frekuensi	5	>10^-2					
	4	(10^-3) - (10^-2)					
	3	(10^-4) - (10^-3)					
	2	(10^-5) - (10^-4)					
	1	<10^-5					W,X,Y,Z
Low Risk			<0,083	0,083-0,235	0,235-0,433	0,433-0,667	>0,667
Medium Risk			1	2	3	4	5
High Risk			Konsekuensi (KJ)				

Fig. 6. Risk Matrix 2870 kg Anchor Against Pipeline A

RISK MATRIX							
Frekuensi	5	>10^-2					
	4	(10^-3) - (10^-2)					
	3	(10^-4) - (10^-3)					
	2	(10^-5) - (10^-4)					
	1	<10^-5					W,X,Y,Z
Low Risk			<0,977	0,977-2,764	2,764-5,077	5,078-7,818	>7,818
Medium Risk			1	2	3	4	5
High Risk			Konsekuensi (KJ)				

Fig. 7. Risk Matrix 2870 kg Anchor Against Pipeline B

From the risk matrix above, it is necessary to take mitigation steps to reduce the level of risk by determining the thickness of the concrete. Table 5 shows the required concrete coating thickness in order to reduce the risk level. Figure 8 to Figure 11 show risk matrix after concrete coating is applied to the pipeline. From this figures, it can be observed that the use of concrete coating can reduce the risk level for all cases to a low risk category (marked by a green area), which means the pipeline will remain in a safe condition from the potential hazardof being dropped and dragged anchors.

Table 6. Concrete Coating Thickness

Cases	Concrete Coating
1590 kg Anchor Against Pipeline A	50 mm
1590 kg Anchor Against Pipeline B	60 mm
2870 kg Anchor Against Pipeline A	80 mm
2870 kg Anchor Against Pipeline B	80 mm

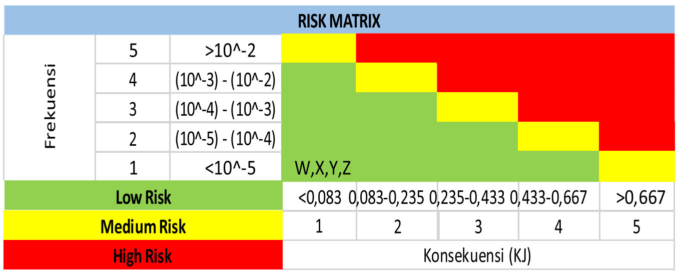

Fig. 9. Risk Matrix 1,590 kg Anchor Against Pipeline A with 50 mm Concrete Coating

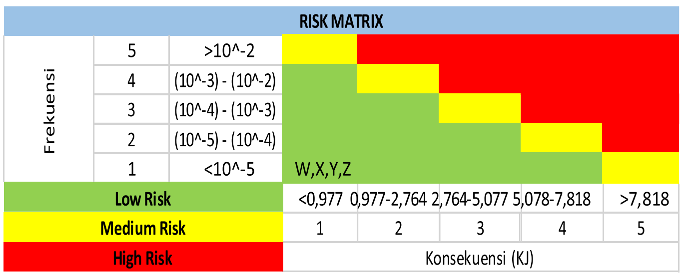

Fig. 10. Risk Matrix 1,590 kg Anchor Against Pipeline B with 60 mm Concrete Coating

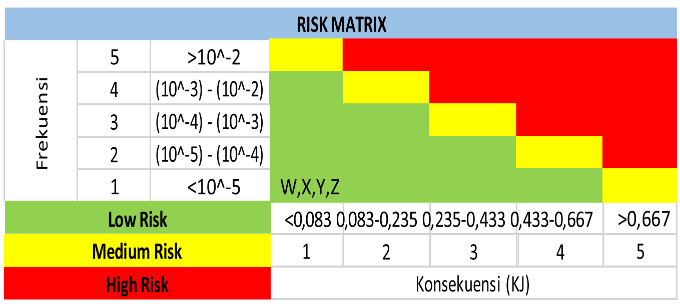

Fig. 11. Risk Matrix 2,870 kg Anchor Against Pipeline A with 80 mm Concrete Coating

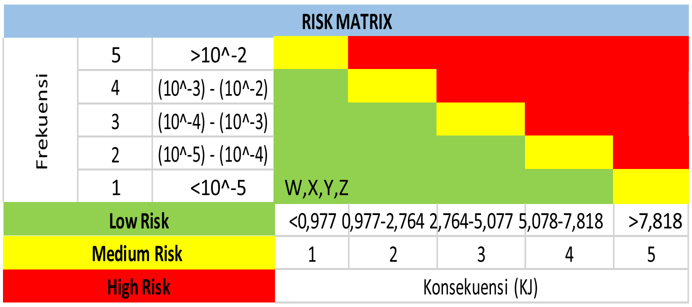

Fig. 12. Risk Matrix 2,870 kg Anchor Against Pipeline B with 80 mm Concrete Coating

4 Conclusion

This paper has demonstrated risk assessment for offshore pipeline due to dropped and dragged anchor using DNV RP F107 and DNV RP F111. Two types of pipelines, namely pipeline A and pipeline B; and two types of anchor, namely anchor with mass 1,590kg and 2,870 kg have been applied for the assessment. From the analysis, it can be observed that for the possible event of dropped and dragged anchor posses low frequency. For all possible event, the consequences of dropped and dragged anchor have been calculated for pipeline without concrete coating. The results show that the pipeline without concrete coating has a medium level of risk. In order for the reduce the risk level, the risk consequence can be lowered by applying concrete coating to the surface of the pipeline. The concrece coating of 50 mm thickness is applied to pipeline A and 60 mm thickness is applied to pipeline B against the 1,590 kg anchor. The concrete coating with 80 mm thickness is applied to both piplineA and pipeline B in order to withstad the 2,870 kg anchor. After applying concrete coating asa mitigation, then based on the risk matrix, the risk level decreases to a low risk category.

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