Evaluation of Underwater Pipeline Design Criteria Due to Safety Requirement based Hydrodynamic and External Load

Widi Agoes Pratikto, Raditya Danu Riyanto, Silvianita, Rendatiyarso Laksono,
Muhammad Ilham Maulana, Wetta Inggrid Sari, Abiyani Choirul Huda and Liany Ayu Catherine
*Department of Ocean Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember,
Surabaya, Indonesia*

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Abstract: Several problems can be solved by piping engineers to protect pipelines so it can be resistant to environmental and man-made hazards. Factors that can damage the pipeline are usually shipwrecks, faults in dropping and pulling anchors, dredging activities, fishing activities, and the exploration of undersea. Burial pipelines are the solutions most often used by engineers for the protective pipeline. However, the burial of the pipeline cannot always be applied due to unfavorable seabed issues or if there are other factors. This paper will explain the results of research related to the pipeline by calculating the dimensions of rock berms to protect pipelines from external loads and analysis of the free span pipeline to check the feasibility of being exposed to environmental loads.

1 INTRODUCTION

The Oil and Gas Industry is an important sector in national development both in terms of meeting the needs of energy and industrial raw materials in the country as well as producing foreign exchange so that the management needs to be done as optimal as possible. The underwater pipeline is one of the most efficient long-distance transportation infrastructure for oil and gas for the transfer of oil and gas production both from exploration on land, near the coast and from the deep sea with effective and efficient methods. Failure in the pipeline system can be caused by various problems, such as free span (due to environmental loads), and anchor loads (external loads) from ships that are leaning in the Madura Strait area. A free span occurs due to vibration or commonly known as the Vortex-Induced Vibration (VIV) phenomenon that occurs in parts of the pipe that touches the seabed. Stability analysis of the pipeline from the environmental load (wave and current) is very important because it can determine feasibility design of the pipeline (length of the free span) that has been installed so that in the future preventive steps can be planned for the best. Pipeline protection from external loads is also important because if the pipeline is hit by anchor load it can cause damage such as buckling and pipe leakage so that it disrupts the oil and gas distribution process and causes environmental pollution.

2 RESEARCH DATA

In this study, the area to be analyzed is the Madura Strait, and the pipeline that will be designed for rock berm protection and free span analysis are the Block BD pipeline. In the analysis of concrete armor design (rock berm) design, an external load size calculation will be performed. External loads have a big role in damaging the pipeline system on the seabed, in this case, the movement anchor from the seabed. In determining the size of the anchor, an analysis of ship mobility that often crosses the study area will be carried out, namely the Madura Strait. The following are the data used in this study:

Table 1: Ship Sailing Data in the Madura Strait.

(source: PT. Pelindo III)

Ship Type	In 2012
Container Ship	2040
General Cargo Ship	2144
Bag Cargo Ship	558
Fuel Tank Ship	1264
Liq. Bulk Non Fuel Ship	447
Dry Bulk Ship	616
Barge	5908
Passenger Ship	1889

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Table. 2: Ship Capacity Data in the Madura Strait.

(source: PT. Pelindo III)

Ship Type	Max. Capacity
Passenger Ship	15.000 GT
Cargo Ship	5.000 DWT
Ferry Ship	10.000 DWT
Roro Ship	5.000 DWT
Tanker Ship	5.000 DWT

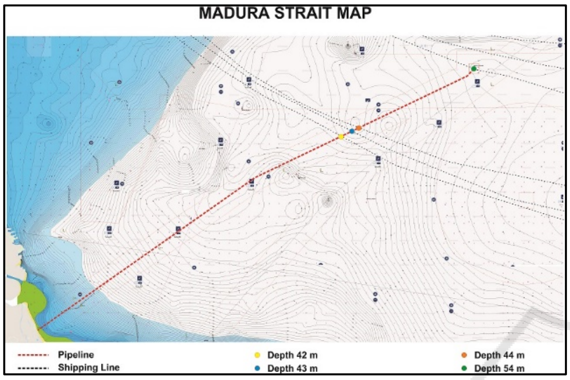

Figure 1: The waters map in the Madura Strait (source : navionics.com and maps.google.com).

In this study for wind data, current velocity, and wave data are at coordinates with longitude 113.066248 E and Latitude 7.567736 S over 5 years namely 2014-2019 with ground data using granules D50 = 0.03 m.

Table 3: Wind Data in the Madura Strait.

Date	Time (GMT +7)	Wind Dir (deg)	Wind Speed (knot)	High Wave Sign. (m)	Curr. Speed (cm/s)
01-12-2014	00.00	169.26	3.4	0.01	0.51
02-12-2014	01.00	173.02	3.56	0.01	0.62
03-12-2014	02.00	176.46	3.72	0.01	0.69
…	…	…	…		
13-07-2019	17.00	144.27	2.08	0.01	4.28
14-07-2019	18.00	139.43	1.99	0.01	4.45
15-07-2019	19.00	134.2	1.93	0.01	4.61

Table 4: Pipeline Data.

Parameter	Value	Unit
Inner diameter of pipe	404.14 (16)	mm (inch)
Wall thickness of pipe	13 (0.5)	mm (inch)
Wall thickness of concrete	60 (2.4)	mm (inch)
Nominal diameter	0.45	m
Allowable free span	23.8 (78)	m (ft)
Length of pipe	53	km
Effective Mass	282.68	kg/m
Period	20	year

3 RESEARCH DATA PROCESSING

3.1 Free Span Calculation

Free span calculation is used to determine the maximum span length so that the stress that occurs in the free span does not exceed the yield stress of the pipe material. The flow of waves and currents that arise around the pipe, arises a vortex that results in pressure distribution. This vortex produces oscillations/vibrations in the pipe. If the frequency of this vortex approaches the natural frequency of the pipe, resonance occurs, and this causes fatigue in the pipe (Yong Bai, 1981).

3.2 Calculation of Critical Span Length

In Boyun Guo (2005), critical span length or pipe length without support where oscillations occur due to currents is a relationship between the natural frequency of the pipe span and the reduced velocity. The critical span length for cross-flow motion is

$$L_s = \sqrt{\frac{C_e\, U_r D}{2\pi}\sqrt{\frac{EI}{M_e}}} \tag{1}$$

In Boyun Guo (2005), the natural frequency of a pipe depends on the stiffness of the pipe, the condition of the end of the pipe span, the span length, and the effective mass of the pipe. The natural fermentation equation of the pipe is as follows:

$$f_n = \frac{C_e}{2\pi}\sqrt{\frac{EI}{M_e\, L_s^4}} \tag{2}$$

Fn = frequency of pipe natural (Hz)

Ls = longspan (m)
Me = massa of effectivity pipe (kg/m)
Ce = 9.87 pin-pin
E = 2.07 E+11 (N/m^2)
I = 0.00018 (kg/m^2)

The critical span lengths for in-flow motion are:

$$L_s = \sqrt{\frac{C_e f_n}{2\pi}\sqrt{\frac{EI}{M_e}}} \tag{3}$$

Ls = Span long of critical (m)
Ce = Span end constants
Ur = Reduced Velocitty (m/s)
D = Diameter of outer pipe (m)
Me = Mass of effectivity pipe, (kg/m)

After the calculations we have:

Table 5: Critical length of span.

Parameter	Water Depth			
	42 m	43 m	44 m	54 m
U_r cross flow	5	4.7	4.8	5
U_r in flow	1.4	1.4	1.4	1.4
L_s cross flow (m)	34.57	33.52	33.87	34.57
f_n	0.48	0.51	0.5	0.48
L_s in line (m)	**16.49**	**17**	**16.83**	**16.49**

For most projects, the allowable span length is the critical span length calculated for in-line motion. However, when economic factors are taken into consideration, the length of the critical range calculated for the cross-flow movement can be chosen.

3.3 Free Span Due to Scouring

Spans in the pipeline can arise due to local scour of sea-floor sediments or where the pipe routes through the seabed are irregular. When the lower current passes through the pipe, separately vortices are formed from the top and bottom of the pipe. This causes fluctuations in hydrodynamic forces which can produce large oscillations or spans in the direction of cross-flow when the frequency of vortex shedding approaches the natural span of vibration. Pipe failures which can be caused by vortex movement can be prevented if the vortex shedding frequency is far enough from the natural frequency of the pipe stretch so that the dynamic oscillation of the pipe can be minimized. The frequency of vortex shedding can be written:

$$f_s = \frac{S\,V_{eff}}{D} \tag{4}$$

fs = frekuensi vortex shedding
S = Strouhal Number
Ve = effective current speed (m/s)
D = Diameter of Pipe (m)

Strouhal number is a function of Reynolds' number of current flow. The drag coefficient is also a function of Reynolds' number.

The relationship between the drag coefficient with the Strouhal number is:

$$S = \frac{0,21}{{C_d}^{0,75}}$$

For practical problems, usually, the Strouhal number is taken at 0.2.

After calculating the results obtained as follows:

Table 6: Free Span.

Parameter	Water Depth			
	42 m	43 m	44 m	54 m
S	0.207	0.201	0.195	0.183
Free Span	0.147	0.131	0.116	0.043

Mousselli (1981) states that the pipeline stretch has begun to oscillate when the shedding frequency is 1/3 of the natural frequency of the vibration of the pipe stretch. To design pipe vortex shedding frequency comparison is smaller than 0.7 times the natural frequency of the pipe stretch so that oscillation does not occur. So it can be written that oscillation does not appear if: fs ≤ 0.7 fn. Based on calculations and limitations that fs ≤ 0.7 fn, the pipe design in the BD block is feasible when viewed from the scouring analysis of the free span, namely:

Table 7: Analysis of freespan.

Water Depth	Parameter			Check
	fs	fn	0.7 fn	OK / NOT OK
42 m	0.147	0.477	0.334	OK
43 m	0.131	0.507	0.355	OK
44 m	0.116	0.497	0.348	OK
54 m	0.043	0.477	0.334	OK

4 ANCHOR CALCULATION

4.1 Calculation of the Main Dimensions of the Ship

Anchor calculations are performed to determine dimensions, number of anchors needed, anchor weight, and chain dimensions. In this study, the anchors of a 15000 GT Passenger Boat with 10000 DWT Ferry Ships will be compared with the following data:

Table 8: Data of Ship Comparison for Passenger Ship 15000 GT.
(source: equasis.com)

Ship Name	GT (m^3)	DWT (ton)	Lpp (m)	B (m)	T (m)	Vs (knot)
Nggapulu	14739	3175	146.5	23.4	6	15.6
Sinabung	14716	3485	146.5	23.7	6	16.3
Bukit siguntang	14643	3686	146.5	26.5	5.7	15.5
Ciremai	14581	3480	144.8	26.8	5.5	16
Dobonsolo	14581	3500	146.5	23.7	6	15.7
Doro londa	14685	3175	146.5	23	5.9	15.1
Kambuna	14501	3434	144.8	23.7	5.9	17.4
Kelud	14665	3537	146.5	23.7	5.8	17.3
Lambelu	14649	3685	136.03	23.7	5.5	15.9
Rinjani	14501	3434	144.8	23.7	5.7	17.1
Tidar	14501	3200	144	23.7	6.1	15.4
Umsini	14501	3434	141	22	6	12.5

Table 9: Data of Ship Comparison for Ferry Ship 10000 DWT.
(source: equasis.com)

Ship Name	GT (m^3)	DWT (ton)	Lpp (m)	B (m)	T (m)	Vs (knot)
Europalink	9653	46124	218.8	30.5	6.9	14.7
Finnlady	9653	45923	218.72	30.52	6.8	22.6
Finnmaid	9653	45923	218.77	30.5	6.7	21.3
Finnstar	9653	45923	218.77	30.5	6.7	21.6
Finnswan	9653	45923	218.8	30.5	6.9	14.9
La superba	9750	49257	211.5	30.4	7.3	22.7
La suprema	9720	49257	211.5	30.4	7.2	22.8
Skane	8787	42705	200.2	29.6	5.9	11.2
Spirit of britain	9500	47592	212	31.4	6	16.7
Spirit of france	9884	47592	212	31.4	6	14.8
Stena adventurer	9487	43532	211.56	29.88	5.5	19
Ulysses	9665	50938	209.08	31.84	6.3	18.7

From comparison ship data tables 3.5 and 3.6 can be made the relationship graph between GT and DWT, GT with Lpp, GT with B, GT with T, and GT with Vs for 15,000 GT Passenger Ship and also graph the relationship between DWT and GT, DWT with Lpp, DWT with B, DWT with T, and DWT with Vs for 10,000 DWT Ferry Ships to determine the size of the main dimensions of the ship to be measured anchored using linear regression equations.

After obtaining a graph from the comparison, from the linear regression above (each equation), the values of the main dimensions of the 15,000 GT Passenger Boat and the 10,000 DWT Ferry Ship are as follows:

Table 10: The Main dimensions of Passenger Ships 15000 GT.

Parameter	Value	Units
GT	15000	m^3
DWT	3429.5	ton
Lpp	148.58	m
B	25	m
T	6	m
Vs	15.68	knot

Table 11: The Main Dimensions of Ferry Ships 10000 DWT.

Parameter	Value	Units
DWT	10000	ton
GT	50156	m^3
Lpp	221.5	m
B	30.3	m
T	6.5	m
Vs	19.2	knot

4.2 Determination of Ship Coefficient

Based on Froude numbers, CB can be calculated with the formula Watson-Gilfilla, CM, and CWP can be searched by equations in the book "Parametric Ship Design" page 11. Furthermore, the length of LWL, LCB, ∇, and Δ can be calculated, which are:

$$\text{Froude Number (Fn): } \frac{Vs}{\sqrt{g\ Lpp}} = 0.412 \qquad (5)$$

$$\text{CB : Block Coefficient:}$$
$$-4.22 + 27.8 \cdot \sqrt{(Fn\ )} - 39.1 \cdot Fn + 46.4 \cdot Fn \qquad (6)$$

$$\text{CM: Midship Coefficient: } 0.977 + 0.085 \cdot B - 0.6) \qquad (7)$$

$$\text{CWP: Waterplane Coefficient: } 0.180 + 0.860 \cdot CP \qquad (8)$$

$$\text{LCB: Longitudinal Center of Buoyancy:}$$
$$8.80 - 38.9 \cdot Fn \qquad (9)$$

$$\text{CP: Prismatic Coefficient: } C\_B/C\_M \qquad (10)$$

$$\nabla\text{: Volume Displacement: } L \cdot B \cdot T \cdot CB \qquad (11)$$

$$\Delta\text{: Displacement: } \nabla \ .\ \rho \qquad (12)$$

Where, **ρ = 1.025 ton/m3**

Based on the explanation and formula above the results of the calculation of the coefficient of the ship based on the dimensions of the ship obtained are as follows:

Table 12: The dimensions of the Passenger Ship 15000 GT based on the coefficient of the ship.

Parameter	Value	Unit
Cb	0.75	-
Cm	0.99	-
Cp	0.76	-
Cwp	0.84	-
Lcb	7.19	behind of the midship
Δ	805.69	m^3
∇	825.83	ton

Table 13: The Dimensions of the Ferry Ship 10000 GT based on the coefficient of the ship.

Parameter	Value	Unit
Cb	0.76	-
Cm	0.99	-
Cp	0.77	-
Cwp	0.84	-
Lcb	7.23	behind of the midship
Δ	1075.29	m^3
∇	1102.17	ton

4.3 Anchor Dimensions and Weight

Based on BKI Vol. II of 2001 section 18-2, the Z number can be calculated using the following formula:

$$Z = D2/3 + 2.h.B + A/10 \qquad (13)$$

Where,

D2/3: Represents the amount of water displaced (displacement) when the waterline is in summer in seawater which has ρ seawater 1.025 tons / m3

H: The effective height is measured from the line of loading water in summer to the highest end of the deck.

B: Ship Width

A: The area (m2) is the appearance of the hull profile, superstructure and houses which have a width greater than B / 4 which is above the loading line in summer including length L and above from height h.

LWL: LPP + (3% * LPP)

D2/3: (LWL x B x T x CB)2/3

In calculating h, it is assumed to be the upper building and the deck is 2.4 m, so the upper building and house building

h : Fb + ∑h
: (H-T) + (Number of Floors x Floor Height)
A: LWL x T

Calculate Equipment Number (Z) with the following equation:

$$Z: D2/3 + (2 \times h \times B) + A/10 \qquad (14)$$

After calculating the results obtained are as follows:

Table 14: Calculation of Equipment Number (Z) of Passenger Ship 15000 GT.

Parameter	Value	Unit
Lwl	153	m
D2/3	664.76	-
H	14.06	-
A	911.23	-
Z	1456.1	-

Table 15: Calculation of Equipment Number (Z) of Ferry Ship 10000 DWT.

Parameter	Value	Unit
Lwl	228.14	m
D2/3	1048.2	-
H	15.43	-
A	1475.2	-
Z	2129.8	-

Based on the calculation, the Z value of the 15,000 GT Passenger Ship is 1456,104 while the Z value of the 10,000 DWT Ferry Ship is 2129.88. From the results of calculations prove that the 10,000 DWT Ferry has a Z value greater than the Z value of the 15,000 GT Passenger ship. Because the greater the Z value, the greater the anchor obtained from the BKI table, so in this study we used the Z value of the 10,000 DWT Ferry with a Z value of 2129.88.

Based on the table BKI Volume II 2006 section 18, then with a value of Z = 2129.79 obtained anchor data as follows.

- Number of anchor bower:2 anchr
- Anchor Bower Weight : 6450 kg
- Anchor Chain
  Length : 605 m
  Diameter D1 : 81 mm
  D2 : 70 mm
  D3 : 62 mm
- Mooring Rope
  Amount : 5 pieces
  Length : 200 m
  Broken Load : 425 kN
- Pull Rope
  Length : 240 m
  Broken Load : 1260 kN

  Anchor weight = 6450 kg, then from the catalog obtained anchor dimensions that will be used on this ship are:

  A = 2920 mm
  B = 2046 mm
  C = 906 mm
  D = 1885 mm
  E = 1461 mm
  ǾF = 110 mm

4.4 Anchor Chain Determination

After getting the data from the anchor, the anchor chain is selected from the catalog, namely by:

a. Total Length Selected: 605 m
b. Diameter of chain anchor selected: 81 mm
Komposisi dan kontruksi dari rantai jangka meliputi:

1. Common link
   1). 1,00 d = 81 mm
   2). 6,00 d = 486 mm
   3). 3,60 d = 291.6 mm
2. Enlarge Link
   1) 1,1 d = 89.1 mm
   2) 6,6 d = 534,6 mm
   3) 4,0 d = 324 mm
3. End Link
   1) 1,2 d = 97,2 mm
   2) 6,75 d = 546,75 mm
   3) 4,0 d = 324 mm

Based on the calculation of the dimensions that have been obtained the following is an illustration of the anchor size obtained from the calculation results based on table Z BKI.

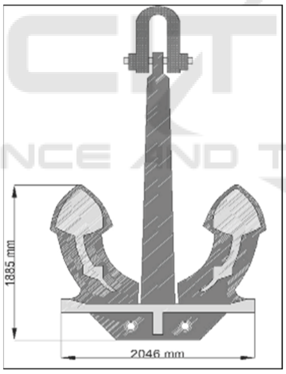

Figure 2: The dimension of anchor in the front look.

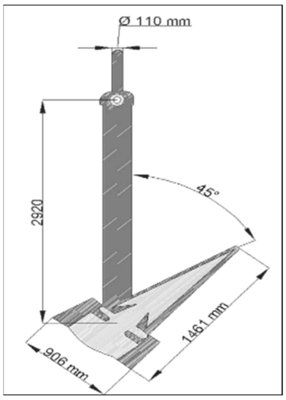

Figure 3: The dimension of anchor in the beside.

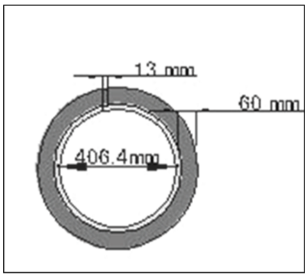

Figure 4: The dimension of pipe and layer in the concrete.

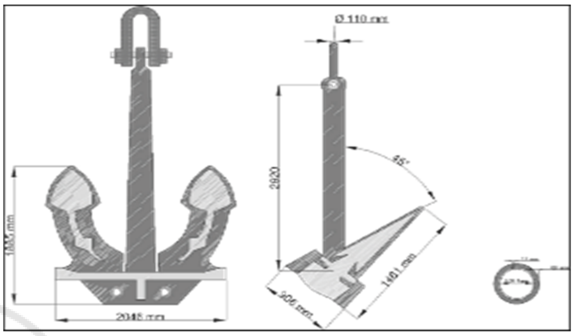

Figure 5: The comparison of Anchor and Pipe.

5 CALCULATION OF ROCK BERM

The use of berm rock is a common practice to protect pipes against collisions from fishing gear such as trawlers and trawlers. Rock berms must be able to withstand horizontal impact loads, which mainly depend on the following:

- The shape and mass of a trawler
- Trawling speed
- Direction of attraction
- Seabed conditions

5.1 Dimensions of Rock Berm

The rule of thumb for the design of suitable protection against anchor anchors has been derived from tests carried out for 20 years and is mainly used in connection with the following rock berm parameters:

- Protective stone size (D50)
- The thickness of the protective layer
- Filter layer thickness (if applicable)
- Minimum width of the rocky peak
- Minimum width of the berm rock base

Below is a visualization of the structure of berm rock based on the calculations:

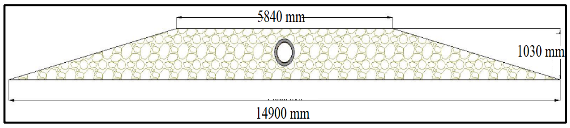

Figure 6: Rock berm illustration.

Based on calculations, the dimensions of the stone which can be sufficient against the drag anchor are as follows:

Table 16: Rock Berm Dimension.

Rock berm dimension	Value
$D_{50,\text{ armour}}$	• 4 * 81 mm = 0.32 m
$H_{\text{min, armour}}$	• 1.46 m * sin(45) = 1.03 m • 3 * 0.32 m = 0.97 m
$H_{\text{min, filter}}$	• 1.5 * 0.32 m = 0.49m • 0.3 m
$B_{\text{min, top}}$	• 2 * 2.92m = 5.84m
$B_{\text{min, bottom}}$	• 5.84 m + 2*2.5*(1.33+0.48 m) = 14.9 m

6 CONCLUSION AND SUGGESTION

6.1 Conclusion

Based on the analysis, the free span parameters in the pipeline show that they are still feasible and do not require handling to overcome the free span. the pipeline design to free span with a limit of fs ≤ 0.7 fn: (Refer to **Table 7**).

Furthermore, from the analysis of the anchor weight, the dimension of berm rock which is used as protection for pipeline on the bottom of the sea from anchor threats. Dimensions of rock berms are:

B_{top} : 5.84 m
B_{bottom} : 14.9 m
H_{armour} : 1.03 m

(Refer to **Table 16).**

6.2 Suggestion

The suggestion of this research is:
When doing free span calculations it would be better if done with 3D modeling, the author has not done 3D modeling to provide a clearer visual appearance to the reader.

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