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On-Bottom Stability Analysis of Submarine Pipelines Based on DNVGL RP F109

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Abstract

Submarine pipeline must be design as stable as possible to prevent failure, considering the external forces from current, wave and soil conditions. Based on these problems, the on-bottom stability analysis needs to be considered in the design of the submarine pipeline by referring to the requirements set out in the DNVGL RP F109 2017. The results of the analysis are the value of hydrodynamic force in the horizontal direction which are 99,916 N/m and 204,358 N/m for installation and operating conditions respectively, while the hydrodynamic force in the vertical direction for installation conditions is 46,852 N/m and operating conditions is 192,232. N/m. The result of absolute lateral static stability analysis, the pipe with a concrete coating thickness of 40 mm both in installation and operating conditions is stable, because it has met the criteria. The result of generalized lateral stability analysis, in installation conditions, the displacement of 0,5 and 10 times of pipe diameter have reached the safety factor. Meanwhile, in operating conditions, the displacement of 0,5 times of pipe diameter has not reached the safety factor, while for displacement of 10 times the pipe diameter is alright. Therefore, the concrete ballast thickness needs to be added to become 44 mm. Modeling using ANSYS CFX software was carried out to obtain the value of hydrodynamic forces acting on the pipe. The result of pipe modeling in installation conditions are 83,578 N/m and 57,13 N/m for hydrodynamic forces in the horizontal and vertical directions. The model is verified and categorized as a good numerology and modeling due to the simple data and information as an input in ANSYS CFX.

1. Introduction

Oil and gas are still the main material to provide human activities, therefore they were still produced and explored in many ways to meet the demand. Currently, oil and gas exploitation development activities are shifting to the deep sea, so that to distribute oil and gas, submarine pipelines are needed. Submarine pipelines are used to help transport refined oil from one platform to another, transport oil from drilling wells to production facilities, and channel water or chemicals to support production activities. The submarine pipe that is located above the seabed experiences hydrodynamic forces due to wave and current loads. When the hydrodynamic forces that hit the underwater pipe are large enough, the pipe is unstable horizontally and vertically [1-3]. If this is not taken seriously, the submarine pipeline can fail, causing enormous economic and environmental losses [4,5]. Thereby, for pipeline design, stability analysis is needed to minimize the potential for failure that occurs. Another purpose of the stability analysis of submarine pipelines is to choose the right pipeline route, material, size and method of manufacture, installation, and maintenance which is convenient. Therefore, the pipeline can withstand possible currents and wave loads of design at a low cost [1,6]. Calculation of the stability of the submar ine pipe is carried out to determine the minimum weight for the submerged pipe.

Many complex problems occur in pipe stability that make more research or studies were carried out to solve this problem. DNV (Det Norske Veritas) in 1988 published DNV RP E305 as a recommended practice for on-bottom stability analysis referring to the hydrodynamic study in the field conducted by SINTEF in 1983-1987, it said that the maximum lateral displacement is 20 meters. Then in 2007, the DNV RP F109 was published as the latest recommended practice to replace the DNV RP E305. This change was made because of the reduction of hydrodynamic forces due to permeable seabed, pipe penetration to the seabed, and trenching. Other changes also occur in the maximum allowable lateral displacement to become 10 times the pipe diameter. The first edition of DNV RP F109 came out in October 2007 and was amended twice, in April 2009, and the last in October 2010.

By using a method based on the DNV RP F109 2010, Yu et al. has conducted research on the optimization design of submarine pipeline stability on soft clay by taking into account the dynamic effects when the pipe is being installed and the pipe-soil interaction at touchdown point [7]. The result from that research was found that the on-bottom stability of offshore pipeline on soft clay is very sensitive to the soil and pipe installation parameters also supported by research of [8,9].

Ridlwan et al. has conducted research on on-bottom stability analysis of submarine pipelines under operating conditions in a case study platform in the waters of Cimalaya, West Java, Indonesia [10]. On-bottom stability analysis of submarine pipelines is calculated to determine whether the pipeline is vertically and laterally stable on the seabed due to the effects of hydrodynamic forces acting on the pipeline. The safety factor of vertical and lateral stability is carried out in this analysis as a condition for the stability of the submarine pipeline so that it will get the minimum weight and thickness of the concrete layer that covers the pipe also supported by research of [11,12].

Amalia is about export pipeline that required on-bottom stability analysis, with considering the magnitude of the hydrodynamic force at different depths of the seabed to obtain pipe stability that is in accordance with the vertical and lateral safety factors [13]. In this study, modeling has also been carried out using ANSYS CFX software which aims to validate the calculation results from the criteria derived from the 2010 DNV RP F109 with the results of the analysis.

In 2013 DNV (Det Norske Veritas) and GL (Germanischer Lloyd) merged, resulting in a name change to DNVGL. Then in 2017 DNVGL published the latest recommended practice to replace the 2010 DNV RP F109, namely the DNVGL RP F109 (On-bottom stability design of submarine pipelines) [14]. One of the change substances is the interaction of the pipe with the soil which is transferred to DNVGL RP F114 (Pipe-soil interaction for submarine pipelines) [15].

The main discussion of this study is to analyze the stability of the submarine pipeline in lateral condition based on the project of a company that will replace the oil transport pipeline along 6 km starting from KP 0.198 to KP 6,198 which located in the offshore area of Jatibarang, Indramayu, West Java, Indonesia. The minimum depth of the pipe is 22 m. This lateral submarine pipeline stability analysis was conducted to avoid failures that occur in the pipeline based on the applicable recommended practice, namely DNVGL RP F109 2017 (On-bottom stability design of submarine pipelines) [14]. The flow simulation that happened in the submarine pipeline will be carried out using the ANSYS CFX software for student which is one of the ANSYS Workbench facilities, with pipe modeling that defines the length and diameter of the pipe.

2. Methods

In general, submarine pipes are composed with various layers that have varying types of forming materials and thicknesses. This submarine pipeline consists of steel pipe, anti-corrosion coating, concrete weight coating, field joint coating and marine growth layer. Figure 1 is an illustration of the layers in the submarine pipeline.

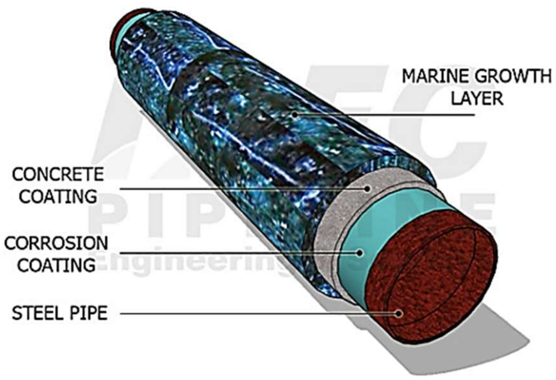

Figure 1. Illustration of Layers on Submarine Pipelines [16]

Submarine pipelines must be designed as stable as possible to prevent failure, considering that it might affected by upward buoyancy, hydrodynamic loads (waves and currents) and soil resistance factors. When the load that was received by the pipe is large enough, it could cause the force that can be destabilize the pipe, resulting vertical and lateral movement. The vertical and lateral stability of the submarine pipeline stability will be based on an analysis that defines the pipeline design parameters required to prevent pipeline movement on the seabed throughout the design life of the pipeline. Figure 2 below is an illustration of the forces acting on the submarine pipeline.

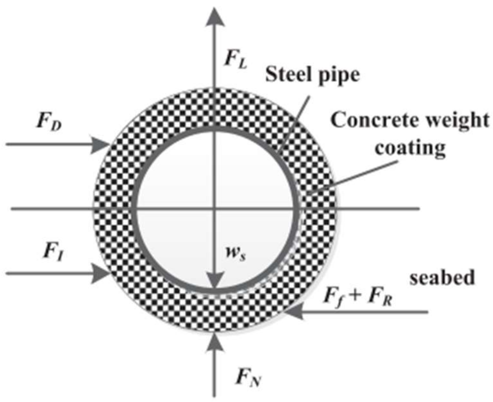

Figure 2. Loading condition of submarine pipeline on seabed [17].

In analyzing the stability of submarine pipelines referring to the 2017 DNVGL RP F109 (On-bottom stability design of submarine pipelines), for lateral stability there are 3 analytical methods that can be applied, namely dynamic lateral stability method, generalized lateral stability method, and absolute lateral static stability method. The choice of this analytical method depends on the level of detail of the analytical results that will be required in the design analysis. The dynamic lateral stability analysis provides general requirements for pipe response with time-domain simulations including hydrodynamic loads from random waves and ground resistance. The generalized lateral stability method and the absolute lateral static stability method will provide specific details regarding the design results for the two stability design approaches. Based on the results of the conditions of currents, waves, and soil as well as the magnitude of the external force that occurs in the pipe, it can be done an analysis related to the stability of the submarine pipeline laterally to meet the criteria value of the absolute lateral static stability method, which is less than or equal to ( ) 1 and reflects the maximum lateral displacement of the pipe of 10 times the pipe diameter based on the generalized lateral stability method that has been set in the 2017 DNVGL RP F109, taking into account the requirements in achieving the safety factor for lateral pipe stability. So, in this study analyze using generalized lateral stability method, and absolute lateral static stability method.

2.1. Generalized Lateral Stability Method

The principle of this method is based on the allowable pipe displacement under certain limit within the design of wave oscillation spectrum with velocity induction on pipe surface vertically. To using this method, the seabed is assuming as flat, bending is neglected, and axial load such us temperature and high operation pressure is neglected, therefore more analysis to achieve safety factor for submarine pipeline is needed. For pipe that has the density more than 3 and less than 1,05, it is not recommended to use this method. The density of pipe is determined by this equation:

$$S_g = 1 + \frac{2}{\pi}.N.K.L \tag{1}$$

For nominal of N, K, and L can be specified by this equation:

$$\mathrm{N} = \frac{\mathrm{U}_s}{g.\mathrm{T_u}} \tag{2}$$

$$K = \frac{\mathrm{U_s T_u}}{\mathrm{D}} \tag{3}$$

$$L = \frac{w_s}{0{,}5\,.\rho_w.D.\mathrm{U}_s{}^2} \tag{4}$$

Within,
K : significant Keulegan-Carpenter number
L : Significant weight parameter
N : Spectral acceleration factor
U_s : Spectrally derived oscillatory velocity (significant amplitude) for design spectrum, perpendicular to pipeline (m/s)
ρ_w : density of sea water (kg/m^3)
T_u : Spectrally derived mean zero up-crossing period (s)
D : pipe outer diameter pipe including all coating (m)

The allowable displacement in this method is 0,5 times of pipe diameter until the maximum limit is 10 times of pipe diameter. The requirement of minimum weight is necessary to restrict the maximum pipe shifting as far as 0,5 times of pipe diameter on soil (clay) seabed. The calculation of pipe minimum weight is using this equation:

$$\mathrm{L_{stable}} = 90\sqrt{\frac{G_c}{N^{0{,}67}.K}\cdot f(M)} \tag{5}$$

For $f(M)$ nominal, it is determined with this equation:

$$f(M) = [0{,}58\,(\log \mathrm{M})^2 + 0{,}60\,(\log \mathrm{M}) + 0{,}47]^{1{,}1} \leq 1{,}0 \tag{6}$$

The minimum weight of pipe shifting until 10 times of pipe diameter in soil (clay) is calculated with this equation:

$$\frac{\mathrm{L_{10}}}{(2+\mathrm{M})^2} = \begin{cases} \mathrm{C_1} + \dfrac{\mathrm{C_2}}{\mathrm{K^{C_3}}} & for\ \mathrm{K} \geq \mathrm{K_b} \\ \mathrm{C_1} + \dfrac{\mathrm{C_2}}{\mathrm{K^{C_3}}} & \text{for } \mathrm{K} < \mathrm{K_b} \end{cases} \tag{7}$$

Within,
G_c : Soil (clay) strength parameter
$f(M)$: the relative function toward the ratio of stable speed and oscillation for spectrum design
M : Steady to oscillatory velocity ratio for design spectrum
C_1 : the coefficient based on DNVGL RP F109 Appendix A
C_2 : the coefficient based on DNVGL RP F109 Appendix A

C_3 : the coefficient based on DNVGL RP F109 Appendix A
K : significant Keulegan-Carpenter number
K_b : equivalent sand roughness parameter

2.2. Absolute Lateral Static Stability Method

Absolute static for submarine pipeline stability laterally is the requirement given for this method based on the static force equilibrium that ensure the pipe resistance toward the movement is sufficient to withstand maximum hydrodynamic force. To fulfill the requirement of absolute lateral static stability method, a pipe must meet the criteria refer to DNVGL RP F109 2017:

$$\gamma sc \cdot \frac{F_y^* + \mu \cdot F_z^*}{\mu \cdot w_s + F_R} \leq 1{,}0 \tag{8}$$

$$\gamma sc \cdot \frac{F_Z^*}{w_s} \leq 1{,}0 \tag{9}$$

Safety factor γ_{sc} for absolute stability at sea in winter can be referenced in DNVGL RP F109 2017. Drag force, inertia force, and lifting force will change to F_y^* (drag and inertia force) dan F_z^* (lifting force) with drag, inertia, and lifting coefficient will be replaced to peak horizontal and vertical coefficient that measured grounded on experiment. Thus, it can be defined as this equation:

$$F_y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_y^* \, (U^* + V^*)^2 \tag{10}$$

$$F_Z^* = r_{tot,Z} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* \, (U^* + V^*)^2 \tag{11}$$

F_y^* : horizontal hydrodynamic load (N/m)
F_z^* : vertical hydrodynamic load (N/m)
r_{tot} : load reduction factor
ρ_w : density of sea water (kg/m^3)
D : pipe outer diameter including all coating (m)
C_y^* : peak horizontal load coefficient (DNVGL RP F109, 2017)
C_z^* : peak vertical load coefficient (DNVGL RP F109, 2017)
U^* : Oscillatory velocity amplitude for single design oscillation, perpendicular to pipeline (m/s)
V^* : Steady current velocity associated with design oscillation, perpendicular to pipeline (m/s)

2.3. Pipe Properties and Environmental Data

The location of this research is in offshore of Jatibarang, Indramayu, West Java. Data for calculation consists of pipe properties and environmental data that show at Table 1 and Table 2 below.

Table 1. Pipe Properties

Description	Symbol	Unit	Value	
			Installation	Operation
Pipe Position	-	-	Seabed	Seabed
Material Grade	-	-	API 5L X-52-PSL-2	
Percentage of Corrosion Allowance	$perc_{ca}$	%	0,0	100,0
Steel Density	ρ_{steel}	kg/m^3	7850	
Pipe Joint	JL	m	12,00	
Outside Diameter	OD	mm	323,90	
Wall Thickness	t_{nom}	mm	12,70	
Corrosion Allowance	CA	mm	0,00	3,18
Anti-Corrosion Coating Thickness	t_{corr}	mm	3,20	
Anti-Corrosion Coating Density	ρ_{corr}	kg/m^3	952,00	
Concrete Coating Thickness	t_{conc}	mm	40,00	
Concrete Coating Density	ρ_{conc}	kg/m^3	3040,00	
Water Absorbtion	Absn	%	0,00	5,00
Content Minimum Density	ρ_{cmin}	kg/m^3	0,00	860,00
Content Maximum Density	ρ_{cmax}	kg/m^3	0,00	860,00

Table 2. Environmental Data

Description	Symbol	Unit	Value	
			Installation	Operation
Minimum Water Depth	D_{min}	m	22,00	
Maximum Water Depth	D_{max}	m	32,40	
Sea Water Density	ρ_{water}	kg/m^3	1025	
Soil Type	-	-	Clay	
Submerged Weight of Soil	γ_{soil}	N.m^{-3}	13451,00	
Clay/Sand Shear Strength	S_u	Pa	4674,00	
Soil Friction Factor	μ	-	0,20	
Current Velocity	V_s	m/s	0,41	0,50
Measurement Height of Current Velocity	z_r	m	1,00	
Significant Wave Height	H_s	m	2,38	3,35
Peak Wave Period	T_p	s	7,30	8,30
Angle between Current with Pipeline Bearing	-	deg	56,00	
Angle between Wave with Pipeline Bearing	-	deg	11,00	

3. Result and Discussions

3.1. Generalized Lateral Stability Method

Tabulation of pipe properties is conducted to find out the pipe outer diameter including all coating that consists of steel pipe, corrosion coating, and concrete coating. The weight of steel pipe, corrosion coating, concrete coating, water absorption on concrete coating and the content of pipe are known as in this processing step as well as the quantity of buoyancy force that applied on pipe. In operation condition, the water absorption on concrete coating and the content of pipe were included to be calculated with considering the corrosion on steel pipe. The result of pipe properties tabulation at installation and operation conditions shows in Table 3.

Table 3. Results of Pipe Properties Tabulation

Description	Symbol	Unit	Value	
			Installation	Operation
Pipe outer diameter including all coating	D_{tot}	mm	410,3	
Steel pipe weight	W_{st}	N/m	955,836	723,822
Corrosion coating weight	W_{acc}	N/m	30,7	
Concrete coating weight	W_{cc}	N/m	1387,26	
Water absorption on concrete coating	W_{abs}	N/m	69,363	0
The content of pipe	W_{cont}	N/m	615,616	0
Bouyancy force	b	N/m	1329,038	

As it shows at Table 3, then the submarine pipe weight can be determined by reducing the total of weight component on pipe with nominal of buoyancy force at pipe. The result of submarine pipe calculations at installation and operation conditions can be seen at Table 4.

Table 4. The result of submarine pipe weight

Description	Symbol	Unit	Value	
			Installation	Operation
Submarine pipe weight	w_s	N/m	1044,758	1497,723

3.2. Current Conditions

Current velocity on pipe can be determined by equation 12 refer to DNVGL RP F109 2017, considering the nominal roughness of clay soil at seabed, which is $5x10^{-6}$ m. The effect of reduction current velocity due to seabed condition and current direction must be taken into consideration to determine current conditions for this study based on equation 13, which is 0,315 m/s for installation condition and 0,384 m/s for operation condition. The result of current velocity on pipe for installation and operation condition shows at Table 5.

$$V_C = V_C(z_r) \cdot \left(\frac{\left(1 + \frac{z_0}{D}\right) \cdot \ln\left(\frac{D}{z_0} + 1\right) - 1}{\ln\left(\frac{z_r}{z_0} + 1\right)} \right) \cdot \sin \theta_c \qquad (12)$$

$$V(z) = V(z_r) \cdot \frac{\ln(z + z_0) - \ln z_0}{\ln(z_r + z_0) - \ln z_0} \cdot sin\theta_c \qquad (13)$$

Within,

Vc : Current velocity average, perpendicular to pipeline (m/s)
$Vc(z_r)$: Current velocity average, perpendicular to pipeline over reference measurement height (m/s)
$V(z)$: Current velocity on pipe elevation (m/s)
$V(z_r)$: Current velocity over reference measurement height (m/s)
z_0 : Bottom roughness parameter (m)
z_r : Reference measurement height over seabed (m)
θ_c : Angle between current direction and pipe
D : Pipe outer diameter including all coating (m)

Table 5. Current velocity on pipe

Description	Symbol	Unit	Value	
			Installation	Operation
Current velocity on pipe	V_C	m/s	0,221	0,269

3.3. Wave Conditions

Referring to DNVGL RP F109 2017, JONSWAP spectrum such as in equation 14 explains the flow condition that reduced by wave. Furthermore, on speed spectrum that reduced by wave on seabed can be determined through wave spectrum transformation on seabed using the first order of wave theory in equation 15. Based on the explanation before, therefore the nominal of spectral moment can be calculated using equation 16, which is the variation of speed and acceleration wave from area below the curve of wave spectrum.

$$S_{\eta\eta}(\omega) = \alpha \,.\, \mathrm{g}^2 . \omega^{-5} . exp\left(-\frac{5}{4}\left(\frac{\omega}{\omega_p}\right)^{-4}\right) . \gamma^{\exp\left(-0,5\left(\frac{\omega-\omega_p}{\sigma.\omega_p}\right)^2\right)} \tag{14}$$

$$S_{UU}(\omega) = G^2(\omega).\, S_{\eta\eta}(\omega) \tag{15}$$

$$M_n = \int_0^{\infty} \omega^n .\, S_{UU}(\omega) d\omega \tag{16}$$

within,

: Generalised Phillips constant
g : Acceleration of gravity (m/s²)
: Wave frequency (rad/s)
ω_p : Peak wave frequency (rad/s)
: peak-enhancement factor
: spectral width parameter
$G(\omega)$: Transfer Function
$S_{\eta\eta}(\omega)$: JONSWAP spectrum
$S_{UU}(\omega)$: The wave induced velocity spectrum at the seabed

Nominal of significant flow velocity amplitude at pipe level and design single oscillation velocity amplitude is considered with reduction factor due to effect of main wave direction and wave dispersion at significant flow velocity. It becomes the projection to pipe normal velocity, within reduction factor can be determined with equation 17. To calculate the reduction factor (R_D), the nominal of specific site spreading parameter (s) is 8 for installation and operation condition. The result of reduction factor affects to the nominal of significant flow velocity amplitude at pipe level and design single oscillation velocity amplitude, and shows at Table 6.

$$R_D = \sqrt{\int_{-\pi/2}^{\pi/2} D_w(\theta) d\theta} \tag{17}$$

Table 6. The value of U* and Us*

Description	Symbol	Unit	Value	
			Installation	Operation
Oscillatory velocity amplitude for single design oscillation	U^*	m/s	0,213	0,378
Spectrally derived oscillatory velocity (significant amplitude) for design spectrum	U_S^*	m/s	0,108	0,192

3.4. Soil Conditions

Hydrodynamic loads in pipe can decrease due to the pipe soil interaction at seabed, referring to DNVGL RP F109 2017. Load reduction factor is divided into 3, they are load reduction factor due to permeable seabed, pipe penetration, and trenching in horizontal and vertical directions. Considering to this study, load reduction factor to be applied is load reduction factor due to penetration. The nominal of penetration depth (z_p) considering the initial penetration (z_{pi}) on soil is 15,374 millimeters for installation condition and 20,288 millimeters for operation condition, within the nominal of soil (clay) strength parameter (Gc) is 0,6333 for installation and operation conditions. The result of load reduction factor due to penetration on installation and operation condition is on Table 7 based on equation 18.

$$r_{tot,i} = r_{perm,i} \cdot r_{pen,i} \cdot r_{tr,i} \tag{18}$$

Within i in equation defines y for horizontal load and z for vertical load.

Table 7. The value of total reduction factor in horizontal and vertical direction

Description	Symbol	Unit	Value	
			Installation	Operation
Load reduction factor in horizontal direction	$r_{tot,y}$	-	0,948	0,931
Load reduction factor in vertical direction	$r_{tot,z}$	-	1,081	1,066

In this analysis, passive soil resistance must be considered due to the requirement of absolute lateral static stability method. The value of passive soil resistance will affect the pipe resistance when the pipe is subjected to hydrodynamic load to decrease the loads. Pipe weight effects towards the value of passive soil resistance. The more weight of pipe, then the penetration of below pipe to seabed become farther from seabed, with the result that it will give the pipe more stable and safer because it can decrease more the hydrodynamic load. The result of passive soil resistance on installation and operation condition shows at Table 8 based on equation 19.

$$\frac{F_R}{F_C} = \frac{4{,}1\,.\,k_c}{\mathrm{Gc}^{0,39}} \cdot \left(\frac{Z_p}{D}\right)^{1,31} \tag{19}$$

Table 8. The result of passive soil resistance

Description	Symbol	Unit	Value	
			Installation	Operation
Passive clay soil resistance	F_R	N/m	127,231	182,968

3.5. Hydrodynamic Forces

Hydrodynamic forces on pipe defines into two directions, that is peak hydrodynamic force horizontal and vertical directions, referring to modification results by DNVGL RP F109 with reference to applied forces on pipe, which are drag, inertia, and lifting forces due to wave and current effects. The nominal of coefficients in peak hydrodynamic force horizontal and vertical can be determined based on Table 9 and Table 10, which is the experiment results done by DNVGL RP F109 2017. The value of peak hydrodynamic force horizontal and vertical directions is calculated with equation 10 and equation 11, and the result is in Table 11.

Table 9. Peak horizontal load coefficient (DNVGL RP F109 2017)

C_Y^*		K^*										
		2.5	5	10	20	30	40	50	60	70	100	≥140
M^*	0.0	13.0	6.80	4.55	3.33	2.72	2.40	2.15	1.95	1.80	1.52	1.30
	0.1	10.7	5.76	3.72	2.72	2.20	1.90	1.71	1.58	1.49	1.33	1.22
	0.2	9.02	5.00	3.15	2.30	1.85	1.58	1.42	1.33	1.27	1.18	1.14
	0.3	7.64	4.32	2.79	2.01	1.63	1.44	1.33	1.26	1.21	1.14	1.09
	0.4	6.63	3.80	2.51	1.78	1.46	1.32	1.25	1.19	1.16	1.10	1.05
	0.6	5.07	3.30	2.27	1.71	1.43	1.34	1.29	1.24	1.18	1.08	1.00
	0.8	4.01	2.70	2.01	1.57	1.44	1.37	1.31	1.24	1.17	1.05	1.00
	1.0	3.25	2.30	1.75	1.49	1.40	1.34	1.27	1.20	1.13	1.01	1.00
	2.0	1.52	1.50	1.45	1.39	1.34	1.20	1.08	1.03	1.00	1.00	1.00
	5.0	1.11	1.10	1.07	1.06	1.04	1.01	1.00	1.00	1.00	1.00	1.00
	10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 10. Peak vertical load coefficient (DNVGL RP F109 2017)

C_Z^*		K^*										
		≤ 2.5	5	10	20	30	40	50	60	70	100	≥140
M^*	0.0	5.00	5.00	4.85	3.21	2.55	2.26	2.01	1.81	1.63	1.26	1.05
	0.1	3.87	4.08	4.23	2.87	2.15	1.77	1.55	1.41	1.31	1.11	0.97
	0.2	3.16	3.45	3.74	2.60	1.86	1.45	1.26	1.16	1.09	1.00	0.90
	0.3	3.01	3.25	3.53	2.14	1.52	1.26	1.10	1.01	0.99	0.95	0.90
	0.4	2.87	3.08	3.35	1.82	1.29	1.11	0.98	0.90	0.90	0.90	0.90
	0.6	2.21	2.36	2.59	1.59	1.20	1.03	0.92	0.90	0.90	0.90	0.90
	0.8	1.53	1.61	1.80	1.18	1.05	0.97	0.92	0.90	0.90	0.90	0.90
	1.0	1.05	1.13	1.28	1.12	0.99	0.91	0.90	0.90	0.90	0.90	0.90
	2.0	0.96	1.03	1.05	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	5.0	0.91	0.92	0.93	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	10	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

Table 11. The result of peak hydrodynamic force horizontal and vertical directions

Description	Symbol	Unit	Value	
			Installation	Operation
Peak hydrodynamic force in horizontal direction	F_y^*	N/m	99,916	204,358
Peak hydrodynamic force in vertical direction	F_z^*	N/m	46,852	192,232

3.6. Analysis of Absolute Lateral Static Stability Method

This method is giving the requirements that the pipe has the resistance to stable and not to move due to the hydrodynamic forces, within pipe resistance factor is from submarine pipe weight and the value of passive soil resistance that applied on pipe. To meet the criteria for this method, therefore equation 8 and equation 9 is applied, and it is necessary to know all aspects of the safety factor (γ_{sc}) such as the classification of the fluid inside pipe, the location, and the safety level referring to DNVGL-ST-F101 [18]. Considering all those aspects, safety factor for installation condition is 1 and for operation condition is 1,4. The result of criteria from the absolute lateral static stability method on installation and operation condition is in Table 12.

Table 12. The value from criteria of Absolute Lateral Static Stability Method

Description	CWC thickness	Depth	Value		The value of criteria
			Installation	Operation	
1st criteria of absolute lateral static stability method	40 mm	22 m	0,325	0,704	1,0
2nd criteria of absolute lateral static stability method	40 mm	22 m	0,045	0,18	1,0

In DNVGL RP F109, it said that pipe is stable if the value from criteria of Absolute Lateral Static Stability Method has less than or equal to one (1). In Table 11, the submarine pipeline, that is located on the depth of 22 meters and having concrete coating 40 millimeters, is fulfill the criteria for absolute lateral static stability for installation and operation conditions to obtain required safety factor. The value of criteria is less than 1, which the 1st criteria is 0,325 and 0,74, and the 2nd criteria is 0,045 and 0,18 for installation and operation conditions, respectively. Then, it can conclude that the submarine pipeline can prevent the possible failure that can happen to the pipe, and the pipe is stable laterally because it can resist from hydrodynamic forces. Thus, the pipe is set properly on seabed for installation and operation conditions.

3.7. Analysis of Generalized Lateral Stability Method

The requirement to using this method relates to minimum weight needed to constraint the pipe shifting as far as 0,5 to 10 times of pipe diameter using equation 5 and equation 7. This method can not be used for pipe that has density more than 3 and less than 1,05, within the nominal of spectral acceleration factor (N) 0,024 for clay soil, and it applies to the soil that has soil (clay) strength parameter (Gc) 2,78. For the requirement of minimum weight needed to constraint the pipe shifting as far as 0,5 times of pipe diameter, it is necessary to have the relative function toward the ratio of stable speed and oscillation for spectrum design ($f(M)$), and the result is 0,69 and 0,54 for installation and operation condition, respectively. Then, significant Keulegan-Carpenter number (K) is obtained, it is 1,987 for installation and 3,876 for operation condition. The value of coefficient and equivalent sand roughness parameter for the requirement of minimum weight needed to constraint the pipe shifting as far as 10 times of pipe is determined by DNVGL RP F109 2017 from documented data based on soil (clay) strength parameter (Gc) is 0,633 for installation and operation conditions, spectral acceleration factor (N) is 0,001 and 0,002 for installation and operation, respectively, and steady to oscillatory velocity ratio for design spectrum (M) is 2,049 for installation condition and 1,405 for operation condition. If there is no data from documentation, it is necessary to do the conservative approximation such as interpolation. The minimum weight needed from generalized lateral stability method shows in Table 13.

Table 13. The minimum weight parameter to constraint pipe shifting

Description	CWC thickness	Depth	Value	
			Installation	Operation
Weight parameter to constraint the pipe shifting as far as 0,5 times of pipe diameter	40 mm	22 m	376,6	202,907
Weight parameter to constraint the pipe shifting as far as 10 times of pipe diameter	40 mm	22 m	58,208	39,529

In this method, submarine pipeline can be defined as safe if the weight parameter to constraint the pipe shifting as far as 0,5 to 10 times of pipe diameter is less than or equal to significant weight parameter which is determined by equation 4, and the result is in Table 14.

Table 14. The result of significant weight parameter

Description	CWC thickness	Depth	Value	
			Installation	Operation
Significant weight parameter	40 mm	22 m	428,16	193,901

As it shows the result in Table 13 dan Table 14, the submarine pipeline in installation condition achieves the safety factor toward the pipe shifting as far as 0,5 and 10 times of pipe diameter, because the results are less than the significant weight parameter, whereas it is not safe in operation condition for pipe shifting 0,5 times of pipe diameter because the result is more than significant weight parameter, but for pipe shifting 10 times of pipe diameter obtains the safety factor in operation condition. Then, the solution for this analysis results to obtain the safety factor for pipe shifting 0,5 times of pipe diameter in operation condition is to add the pipe weight through the thickness addition of concrete coating, from 40 millimeters to 44 millimeters. Another solution can be applied to achieve the safety factor is doing trenching, anchoring, or adding backfill to cover the pipe. However, those 3 solutions must be observed more to have an effective solution considering another considerable detail.

DNVGL RP F109 2017 gives a special note for this method, if the study is in the deep sea, which the possibility of significant Keulegan-Carpenter number becomes very low whereas the current condition gives high steady to oscillatory velocity ratio for design spectrum number, with the result that the requirement weigh is high. It is recommended to apply absolute lateral static stability method that has a chance to show the lower result. This solution also applies to study for defining higher soil (clay) strength parameter.

3.8. Hydrodynamic Forces Modeling

Modeling of this study will define 12 meters of pipe length which is the length of one segment pipe, 410,3 millimeters of total pipe diameter. Modeling is conducted in installation condition. In Figure 3, it shows the model result of submarine pipeline with enclosure box as an area of flow analysis [19].

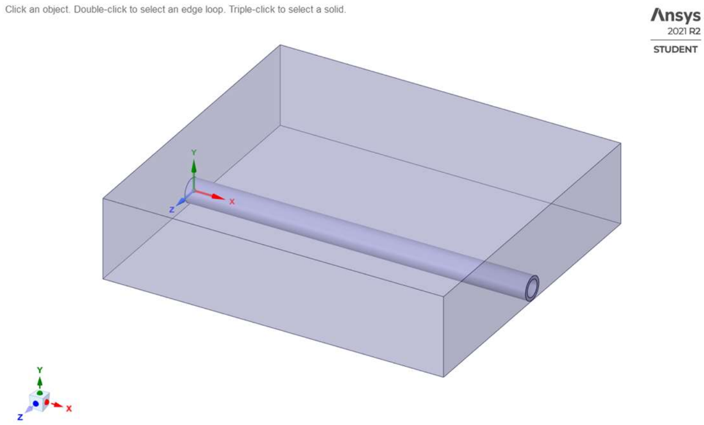

Figure 3. Model of submarine pipeline with enclosure box

First, to setup data for this modeling is defining the material of fluid for this flow analysis, which is sea water with the nominal of density is 1025 kg/m^3. Then, on inlet part for flow velocity, it is divided into two, current flow velocity and wave velocity. Below the pipe is defined as soil which boundary type is wall and the criteria is no slip wall that has nominal roughness is $5x10^{-6}$ m. On the left, right, and top of pipe may define with boundary type is wall and the criteria is no slip wall that has roughness of smooth wall. Figure 4 is the modeling in computational fluid dynamic software.

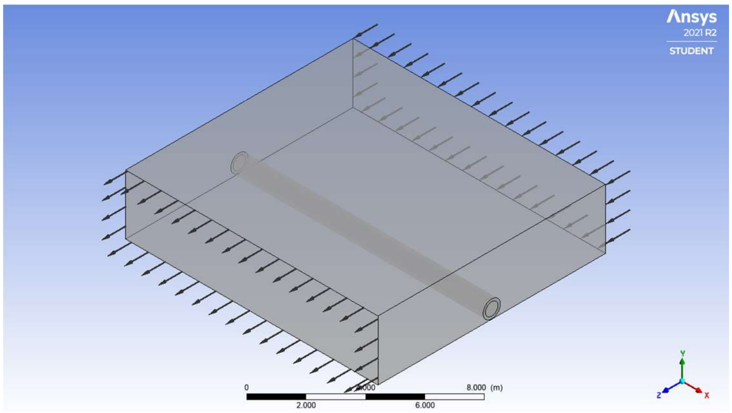

Figure 4. Setup data part for flow analysis

Second, after setup data, running process is conduction to know the model simulation of this study based on the inlet part from current flow and wave velocity. The model simulation shows in Figure 5 and Figure 6.

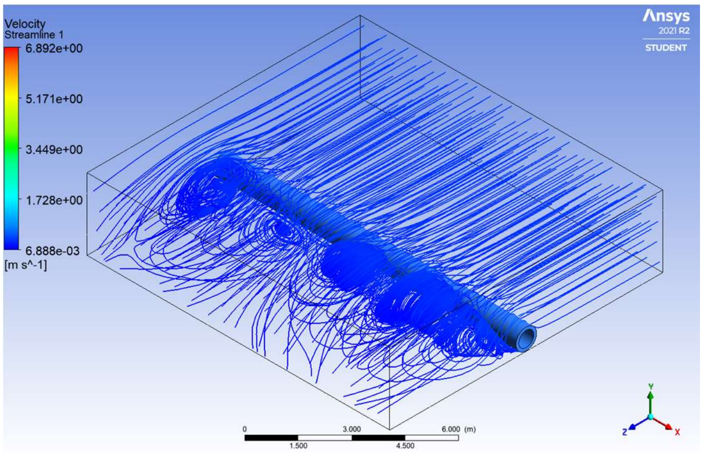

Figure 5. The simulation results of streamline plot with current data inlet

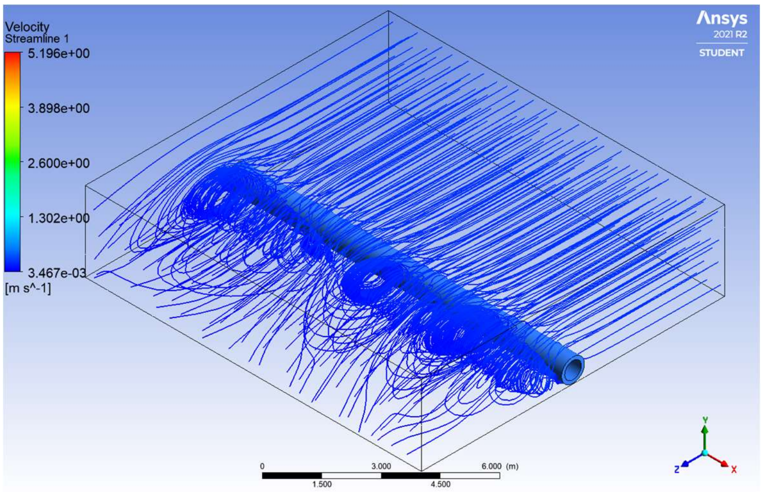

Figure 6. The simulation results of streamline plot with wave data inlet

Finally, based on the results of simulation, hydrodynamic forces that apply on pipe is ascertainable for horizontal and vertical directions. The result of the hydrodynamic forces is in Table 15.

Table 15. The result of hydrodynamic force from modeling

Description	Condition	Unit	Inlet Data	
			Current	Wave
Hydrodynamic force in horizontal direction	Installation	N	667,085	335,861
Hydrodynamic force in vertical direction	Installation	N	471,255	214,312

Based on the results in Table 15, the results of the modeling will be approached first to the calculation results based on the DNVGL RP F109 (Table 11), which will then be compared with the two results which can be seen in Table 16.

Table 16. Comparison of Hydrodynamic Forces between Results from DNVGL RP F109 and ANSYS CFX Software

Description	Condition	Unit	Value		Error
			DNVGL	ANSYS	
Hydrodynamic force in horizontal direction	Installation	N/m	99,916	83,578	22%
Hydrodynamic force in vertical direction	Installation	N/m	46,852	57,13	16%
			Average Error		19%

Table 17. Category on MAPE Method [20]

MAPE	Description
<10%	Highly accurate forecasting
10% - 20%	Good forecasting
20% - 50%	Reasonable forecasting
>50%	Inaccurate forecasting

According to the average error value in Table 16 and based on the description of the error value category of the MAPE method in Table 17, information on a good forecasting numerical approach is obtained.

4. Conclusion

After doing some analysis for this research, the conclusions are:

1. Hydrodynamic forces that apply on pipe due to interaction between pipe and wave, pipe and current, in horizontal direction is 99,916 N/m and 204,358 N/m for installation and operation conditions. And in vertical direction, the results are 46,852 N/m for installation condition, and 192,232 for operation condition.
2. Referring to DNVGL RP F109 2017, on absolute lateral static stability method, pipe is stable in installation and operation conditions because the result has met the criteria for this method, that all the criteria is less than 1. Values of 1st criteria are 0,325 and 0,704 for installation and operation conditions, respectively. Then, results of 2nd criteria are 0,045 for installation condition and 0,18 for operation condition. The submarine pipeline is stable using 40 millimeters concrete coating, as the result of analysis using absolute lateral static stability method. For the other methods, which is generalized lateral stability method, the pipe can be defined as safe until met the safety factor, if the value of minimum weight parameter for pipe shifting as far as 0,5 to 10 times of pipe diameter is less than or

equal to the nominal of significant weight parameter. For installation condition, the significant weight parameter is 428,16. And results of minimum weight parameter for pipe shifting as far as 0,5 and 10 times of pipe diameter are 376,6 and 58,208, respectively. Therefore, the pipe is safe because it fulfills the safety factor criteria. However, for operation condition, the nominal of minimum weight parameter for pipe shifting as far as 0,5 times of pipe diameter is 202,907, whereas the significant weight parameter is 193,901. It is not meet the requirement of safety factor because the significant weight parameter is less than the minimum weight parameter for pipe shifting as far as 0,5 times of pipe diameter. In another hand, the nominal of minimum weight parameter for pipe shifting as far as 10 times of pipe diameter is 39,529, and it defines as safe because the minimum weight parameter is less than the significant weight parameter. The solution for operation condition, in order to meet all the requirements for safety factor, the concrete weight coating is increasing the thickness to become 44 millimeters.

3. The results of calculations of hydrodynamic forces referring to DNVGL RP F109 and the results of hydrodynamic forces from modeling in ANSYS CFX software is verified and categorized as a good numerology and modeling, because the mean error of the results is 19%. The error can be happened because the difference of the input to software and the manual calculation. The data and information that input to the ANSYS CFX software is rather simple than in real study, therefore there are some different results or errors.

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