

Feasibility Study Of Subsea Pipeline Crossing Plan

Abstract

With so many pipelines being built, there is a big possibility that one pipeline will cross another pipeline. Crossing pipes between existing and new pipes can be avoided by creating new pipe routes. Building a new pipeline may cost additional money and time. If the new pipe route is determined to pass through the existing pipe route, then the risks posed must be analyzed because it will affect the existing pipe and the new pipe. In general, failures that occur in pipes are due to the design of pipe wall thickness, pipe stability design, pipe free span design, and pipe stress design when installed using pipelay vessels that are not safe and efficient. Pipe wall thickness design based on the DNV-OS F101 standard explains that the pipe design thickness must be sufficient to withstand working loads such as environmental loads and system pressure. Pipe stability design based on DNV-RP F109 and DNV-RP E305 explains that the pipe design must be in a stationary condition due to vertical and lateral loads. So, several of these references are used to design the crossing pipeline.

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1. Introduction

In one year, Indonesia's population increased by around four million people. As the population continues to increase rapidly, the need to use mineral resources increases. The mineral resources in question are oil and natural gas. In everyday life, oil and natural gas are needed for vehicle fuel, kitchen needs and the chemical industry. This has triggered the exploration and exploitation of mineral resources in Indonesian territorial waters, especially in the high seas, to be carried out more intensively.[1] In exploration and production activities, of course, a tool is needed that can distribute the flow of oil and gas from one point to another. Pipes are a suitable tool for distributing oil and gas, both in terms of exploration production and into the hands of consumers.[2] Subsea pipelines are piping installations that aim to convey fluids (water, oil, gas) through piping installations located on the sea bed (seabed). By using this underwater pipe installation, fluid can be transferred from one place to another, from a production unit to another production unit, from a storage unit to a processing unit, and from a processing unit transferred to a storage unit.[3] Subsea pipelines are critical transportation infrastructure for the offshore oil and

gas industry. With the increasing construction of undersea pipeline networks and the construction of ports on coastlines, cases often occur where the landing sections of undersea pipelines intersect shipping lanes.[4]

Along with the development of Indonesia's oil and natural gas industry sector, many exploitation projects have been carried out in Indonesia. Most of these projects use underwater pipelines as a medium for distributing exploitation results. In the underwater pipeline planning process, problems are often encountered where a submarine pipeline route to be constructed meets a submarine pipeline route that has been constructed from a different previous project (existing pipeline).[5]

One of the critical components in designing a pipeline is determining the underwater pipeline route. As time goes by, oil and gas exploration and exploitation activities are increasingly being carried out so that many underwater pipe structures have been installed on the seabed. So, when a new structure is installed to start exploration and exploitation activities, the underwater pipeline route is designed in such a way that it can be installed safely and at an economical cost. One way is by crossing, namely, a new pipeline installed crosswise over the old pipeline assisted by a supporting structure.[1]

2. Theory And Methodology

Undersea pipe crossing is a condition where there is more than one cable line or undersea pipe that meets each other. So that the undersea pipe to be constructed can still be built according to the route that has been determined but also does not disturb the existing undersea cables or pipes, a subsea pipe crossing is carried out. A general illustration of underwater pipe crossings can be seen in Figure 1.

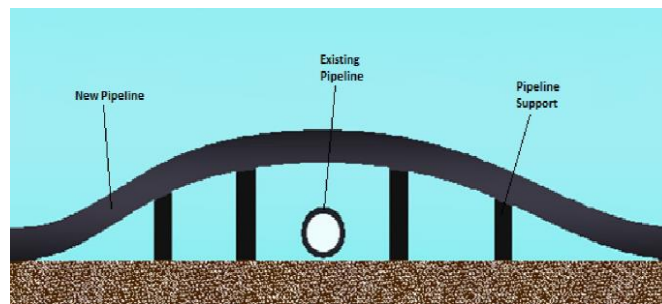


Figure 1. Crossing pipeline sketch

Subsea pipeline design is carried out using a mathematical process that is adapted to international standards. The design process is carried out in three conditions, namely installation, hydration and operation. Installation conditions are conditions when the pipe is not flowing with fluid. A hydro test condition is a condition when a pipe is being tested with a fluid in the form of seawater. Metocean data used in the calculation process for installation and hydro test conditions is a one-year return period data. Meanwhile, operating conditions are conditions when the pipe is flowing with the desired fluid, and the calculation process uses 100-year met ocean data.[1]

The design process begins by determining the pipe wall thickness using calculations from the DNV-OS F101 standard. The pipe wall thickness design must meet four failure design criteria: viz pressure containment, local buckling due to external overpressure, local buckling due to combined loading, and propagation buckling for installation, hydrates and operating conditions. [6] Pressure containment design criteria are carried out to ensure the strength of the pipe to withstand the pressure of the fluid flowing in the pipe so that the pipe figure 1. Crossing pipeline sketches do not explode. The requirements for pressure containment design criteria that must be met can be seen in Equation 1.

$$P_{lx} - P_e \leq \frac{P_b(t)}{\gamma_m \gamma_c} \quad (1)$$

- P_{ix} : Internal pressure at hydrotest conditions (P_{it}) under operating conditions (P_{that})
 $P_{It is}$: External pressure
 $P_b(tl)$: Burst Pressure
 C_m : Material resistance factor
 C_{sc} : Safety class resistance factor

Local buckling in a pipe can be defined as a change in the shape of the pipe to become oval due to the forces experienced by the pipe. A description of local buckling can be seen in Figure 2. [5]

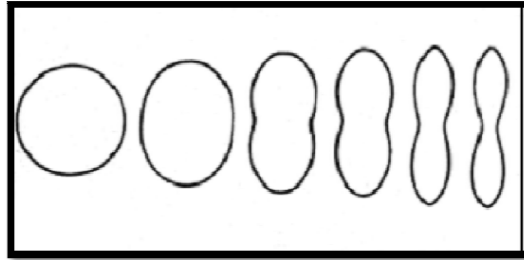


Figure 2. Local buckling on the pipe cross section

The local buckling due to external overpressure criterion is carried out to ensure the pipe's strength in resisting deformation due to external loads in the form of hydrodynamic forces that occur. The requirements for local buckling due to external overpressure design criteria that must be met can be seen in Equation 2.

$$P_e - P_{min} \leq \frac{P_c(t)}{\gamma_m \gamma_{sc}} \quad (2)$$

- $P_{It is}$: External pressure
 P_{min} : Minimum internal pressure that can be maintained
 $P_c(t)$: Characteristic resistance for external pressure

Propagation buckling is when, in cross-section, the pipe changes its configuration to become a buckle that extends and propagates along the pipe and causes the pipe to fail along its path. The principle of buckling propagation is that more significant pressure is required to initiate buckling propagation (called P_{init} initiation pressure) than the pressure required to maintain buckling propagation (called buckle propagation pressure, P_{pr}). The propagation buckling phenomenon can be seen in Figure 3.[5]

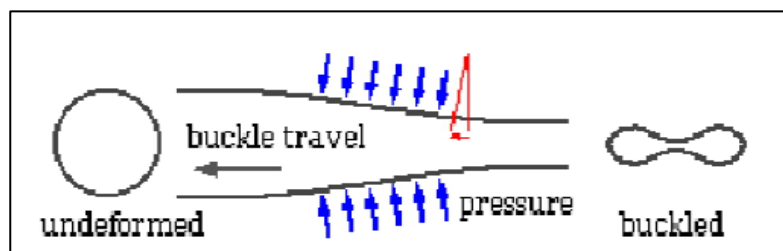


Figure 3. Phenomenon propagation buckling on the pipe

The local buckling due to combined loading criteria is carried out to ensure the strength of the pipe when subjected to a combination of direct loading of bending moment, axial force, excessive internal pressure, and excessive external pressure. The conditions for excessive internal and external pressure can be seen in equations 3 and 4.[6]

Excessive internal pressure condition ($P_i > P_e$)

$$\left\{ \left[\gamma_m \gamma_{sc} \frac{|M_{sd}|}{\alpha_c M_p} + \left(\frac{\gamma_m \gamma_{sc} S_{sd}}{\alpha_c S_p} \right)^2 \right]^2 + \left(\alpha_p \frac{P_i - P_e}{\alpha_c P_b \sqrt{3}} \right)^2 \right\} \leq 1 \quad (3)$$

Excessive external pressure condition ($P_c > P_i$)

$$\left\{ \left[\gamma_m \gamma_{sc} \frac{|M_{sd}|}{\alpha_c M_p} + \left(\frac{\gamma_m \gamma_{sc} S_{sd}}{\alpha_c S_p} \right)^2 \right]^2 + \left(\gamma_m \gamma_{sc} \frac{P_e - P_{min}}{P_c} \right)^2 \right\} \leq 1 \quad (4)$$

- C_m : Material resistance factor
- C_{sc} : Safety class resistance factor
- M_{ad} : Design bending moment
- M_p : Plastic capacities of bending moment
- S_{sd} : Design axial force
- M_p : Plastic capacities of axial force
- α_c : Flow stress parameter
- P_c : External pressure
- P_{min} : Minimum internal pressure
- P_c : Collapse pressure

Next, we review the stability analysis of the underwater pipeline. The pipe will receive loads due to waves and currents on the seabed. The loads due to waves and currents are due to hydrodynamic forces consisting of lift, drag, and inertia forces. In the opposite direction to the hydrodynamic force, the stability of the pipe is also influenced by the frictional force of the soil against the pipe. Stability analysis is divided into vertical and lateral by only reviewing installation and operating conditions. Conceptually, the gravity of a submerged pipe must be greater than the forces acting on the pipe. An illustration of the forces acting on the pipe can be seen in Figure 4.

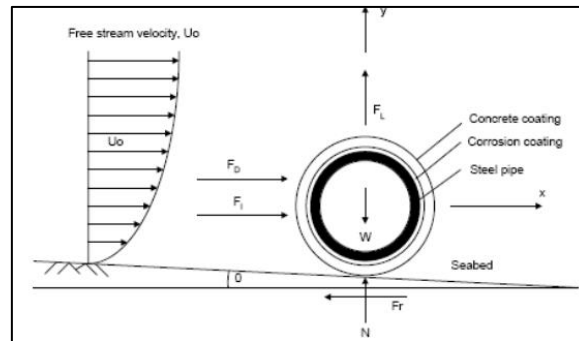


Figure 4. Forces acting on underwater pipes

Based on DNV-RP-E305, vertical stability considers aspects of the subsea pipe's sinking weight and the pipe's lifting force (buoyancy). The total weight calculated comes from the weight of the steel, the weight of the protective layer, corrosion, the weight of the concrete layer, and the weight of other layers. The weight of the concrete layer will be iterated until it meets the on-bottom stability criteria. The pipe is said to be stable in the vertical direction if it meets Equation 5.

$$\frac{\gamma_w}{\frac{W_s + B}{B}} \leq 1 \quad (5)$$

Lateral stability analysis is based on the static equation of the resistance force against the pipe movement response due to hydrodynamic forces. This analysis must satisfy equations 6 and 7.

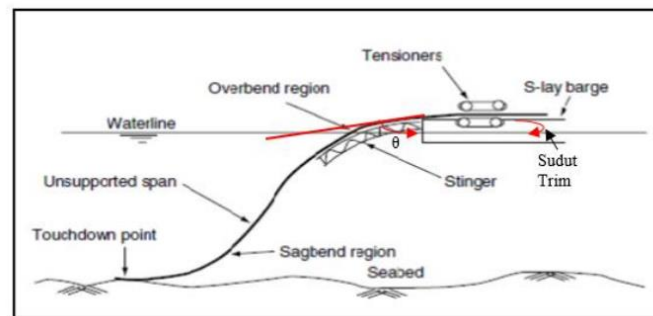
$$\gamma_{SC} \cdot \frac{F_Y^* + \mu \cdot F_Z^*}{\mu \cdot w_s + F_R} \leq 1.0 \quad (6)$$

$$\gamma_{SC} \cdot \frac{F_Z^*}{w_s} \leq 1.0 \quad (7)$$

Table 1. On-bottom stability safety factors

	Rendah	Sedang	Tinggi
Sand and Rock	0.98	1.32	1.67
Clay	1	1.4	1.83

Next is installation analysis. There are installation methods, but this study focuses on the S-Lay installation method. Installation analysis using the static S-Lay method was carried out to determine the configuration of pipelay vessels so that the pipe stress that occurs meets the allowable stress regulated in the DNV-OS F101 standard. The allowable stress is divided into three pipe segments: laybarge, overbend, and sagbend. The allowable stress on the laybarge must not exceed 96% SMYS, overbend must not exceed 85% SMYS, and sagbend must not exceed 72% SMYS. An illustration of the S-lay pipe installation is shown in Figure 5 [1]

**Figure 5.** Illustration of the S-Lay Installation Method

The overbend area extends from the pipe past the ship's stern and then down the stinger to the point where the pipe no longer rests on the stinger. The sagbend area extends from the inflexion point to the touchdown point. The stress in these two areas must be smaller than the permitted yield stress. In the overbend area, the permitted yield stress is 85%, while in the sagbend area, it is 72%. Apart from that, the pipe requirements can be obtained installed well is to have a voltage below 96% of SMYS [[1]].

Free span is a situation where the pipe is not supported on the seabed. The causes of free spans are uneven seabed contours, scouring on the seabed, and crossings that occur with existing underwater pipes. A general description of the free span on a submarine pipe can be seen in Figure 6. So that the underwater pipe does not fail, the maximum length of the free span needs to be known. Pipes with specific free spans can experience oscillations due to VIV (vortex-induced vibrations). Oscillations occur in two directions, namely inline (parallel to the fluid flow) and cross-flow (perpendicular to the direction of the fluid flow). The illustration can be seen in Figure 7.

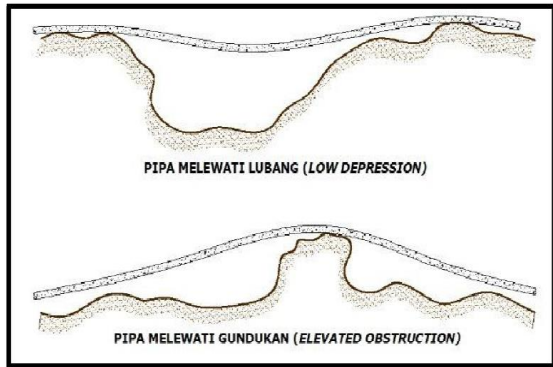


Figure 6. Free Span which commonly occurs in pipes

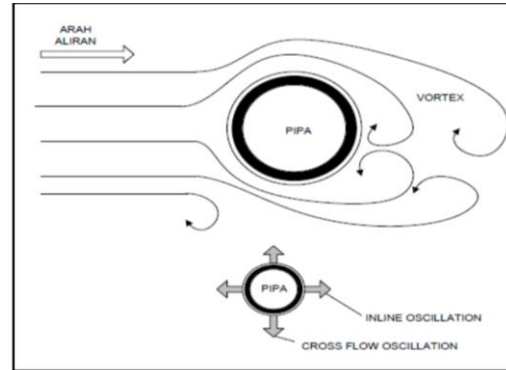


Figure 7. The phenomenon of vortex formation

Pipe-free span analysis is carried out based on the DNV-RP F105 standard. The analysis is a fatigue screening where the pipe's natural frequency will be compared with the load frequency due to vortex-induced vibration (VIV) in the in-line and cross-flow directions. DNV RP F105 states that free span on pipes must meet the requirements of fatigue screening criteria. If the pipe's free span meets these criteria, it has met the fatigue criteria with a life span of 50 years. The fatigue screening criterion states that the pipe's natural frequency must be greater than the pipe's response frequency due to environmental loads. If the pipe response frequency value is the same as the pipe's natural frequency, it will result in a maximum amplitude that can cause the pipe to fail. If the pipe response frequency exceeds its natural frequency, it will result in a small amplitude. However, with faster vibrations, analysing the pipe's fatigue criteria is necessary. Therefore, if the fatigue screening is not met, then fatigue criteria need to be carried out, and if the fatigue screening is met, then it can be continued with the ULS (Ultimate Limit State) check. [5]

Next, an analysis of crossing pipelines is carried out. The support height must be determined to obtain stress and natural bending as permitted to conduct a crossing analysis. If the support height is too high, the stress experienced by the pipe will not meet the permitted stress. Meanwhile, if the support height is too low, natural bending in the pipe will not occur. This crossing support height requirement is determined from the DNV-OS F101 "Submarine Pipeline System" Section 5B design standard, where the crossing pipe must have a minimum distance of 0.3 meters from the existing pipe. An illustration of the crossing pipeline with the existing pipeline is shown in Figure 8.

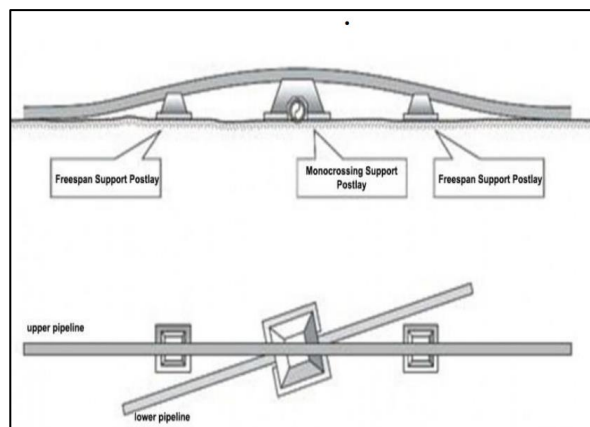


Figure 8. Crossing pipeline dengan existing pipeline

The crossing pipeline analysis uses the ASME B31.8 Chapter VIII standard, where there are three stresses that will be considered: hoop stress, longitudinal stress, and combined stress. The following is one of the studies carried out by Kautsar and Ricky, who tested the design of crossing gas pipelines:

2.1. Thick Pipe Wall Design

The calculation of the minimum thickness of the pipe wall that meets the four design criteria according to the DNV-OS F101 standard is in Table 1.

Table 1. Results of pipe wall thickness calculations

Criteria	Condition		
	Installation (mm)	Hydrotest (mm)	Operation (mm)
Pressure Containment	-	6.35	9.71
Local buckling due to external pressure	3.96	-	-
Propagation buckling	6.35	6.35	7.79
Local buckling due to combined loading	6.35	6.35	7.08
Wall thickness chosen according to design	9.271 mm (0.365 inch) of Pressure Containment (Bursting) design criteria operating conditions		

Based on the calculation results of the four criteria, the most considerable pipe wall thickness is the pressure containment design criterion during operating conditions. The wall thickness above has been given a corrosion allowance to prevent corrosion due to fluid flowing in the pipe during its operational period.

2.2. Thick Pipe Protector Design

Next, design the thickness of the pipe protector resulting from the pipe stability analysis. This design will compare analysis results using the DNV-RP F109 and DNV-RP E305 standards. The thickness comparison results are shown in Table 3.

Table 2. Comparison of pipe protection thickness calculation results based on DNV-RP F109 and DNV-RP E305

Standard Condition	DNV-RP F109		DNV-RP E305	
	Ketebalan Concrete Coating (mm)		Maximum depth	Minimum depth
	Maximum depth	Minimum depth		
Installation	7.7	Installation	15	19
Operation	18.5	Operation	24	40
The thickness of the design used	33.5 mm from installation conditions at minimum depth		-	-

Based on the calculation results of the two tables above, the required thickness of the pipe protective layer for installation conditions is smaller than for operating conditions. This is due to the influence of the hydrodynamic forces that occur, especially the lateral forces of the pipe. The pipe is first analyzed for vertical stability. Vertical stability is helpful to show that the pipe does not float after installed. Then, once the pipe does not float, it is analyzed for lateral stability. Lateral stability is helpful to show that after the pipe is at rest on the seabed, the pipe does not shift laterally due to the hydrodynamic forces that occur. Then, the need for a protective layer for the minimum depth requires a greater thickness because the shallower the water, the more the value of current and wave speed will increase. So, it will produce greater hydrodynamic forces, too.

2.3. Pipe Installation Analysis

The pipe is first analyzed for vertical stability. Vertical stability is helpful to show that the pipe does not float after installation. Then, once the pipe does not float, it is analyzed for lateral

stability. Lateral stability is helpful to show that after the pipe is at rest on the seabed, the pipe does not shift laterally due to the hydrodynamic forces that occur. Then, the need for a protective layer for the minimum depth requires a greater thickness because the shallower the water, the more the value of current and wave speed will increase. So, it will produce greater hydrodynamic forces, too.

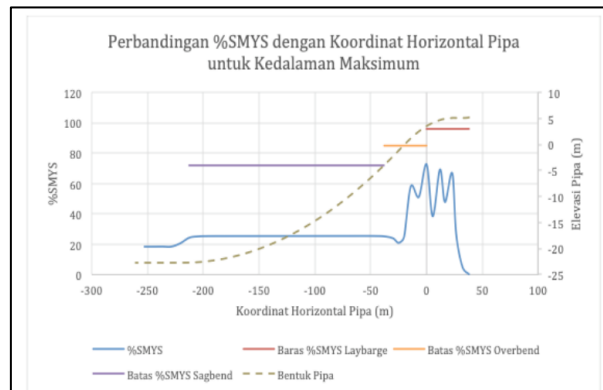


Figure 9. Comparison graph of pipe horizontal coordinates with %SMYS at maximum depth

Based on this graph, the stress values that occur for the three pipe segments are still below their respective allowable stresses, where the stress for the laybarge segment is 72.68% SMYS, the overbend segment is 58.13% SMYS, and the sagbend segment is 25.48% SMYS.

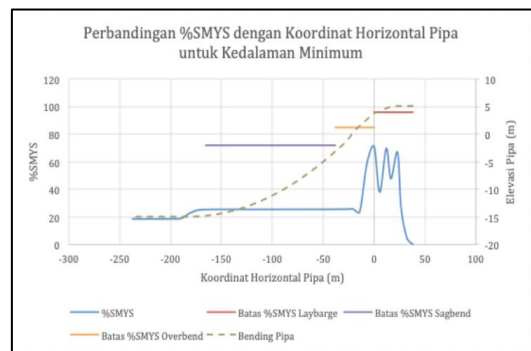


Figure 10. Comparison graph of pipe horizontal coordinates with %SMYS at minimum depth

Based on this graph, the stress values that occur for the three pipe segments are still below their respective allowable stresses, where the stress for the laybarge segment is 71.09% SMYS, the overbend segment is 56.16% SMYS, and the sagbend segment is 25.59% SMYS.

2.4. Free Span Design

The DNV-RP F105 standard analyses static and dynamic conditions in the free-span design. The results of free span calculations for static and dynamic conditions based on DNV-RP F105 are shown in the Table 3.

Table 3. Calculation results of static free span length

Condition	Free Span Length (m)	
	Maximum depth	Minimum depth
Installation	29	29
Hydrotest	20	20
Operation	28	28

In static conditions, the shortest free span is during hydro test conditions. This is because the pipe receives an even load due to hydrodynamic forces, the weight of the pipe, and the fluid, which is heavier than the other two conditions in the pipe. Thus, the pipe has a greater static weight.

Table 4. Free Span Calculation Results for Dynamic Conditions

Condition	Free Span Length (m)	
	Maximum depth	Minimum depth
Installation	27	20
Hydrotest	15	12
Operation	13	9

Based on calculations from the table above, the free span for the installation conditions has the longest free span. This is because the dynamic load received by the pipe is the smallest. The load comes from waves and ocean currents. Installation and hydro test conditions will consider waves with a one-year return period of 1 year, while operating conditions will consider waves with a return period of 100 years. Therefore, the dynamic load under operating conditions will be more significant and result in the shortest or most critical free span.

2.5. Analysis Crossing Pipeline

This pipe-crossing analysis will be modelled using software that uses the finite element method. So, in modelling, the pipe will be made into several elements. The more pipe elements there are, the greater the accuracy in analyzing the occurring stresses. In the analysis process, three factors need to be considered: the height of the support structure, the distance between the support structures, and the settlement that occurs. The results of the crossing pipeline analysis in installation, hydrates, and operating conditions can be seen in Figures 11, 12, and 13.

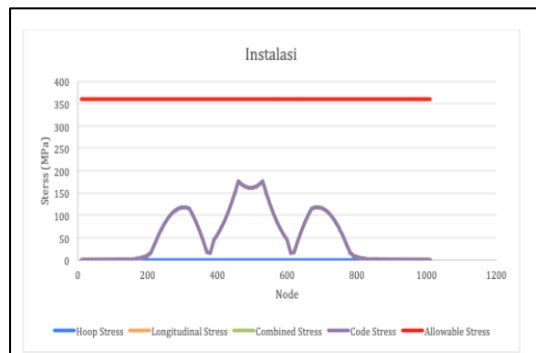


Figure 11. Voltage graph for installation conditions

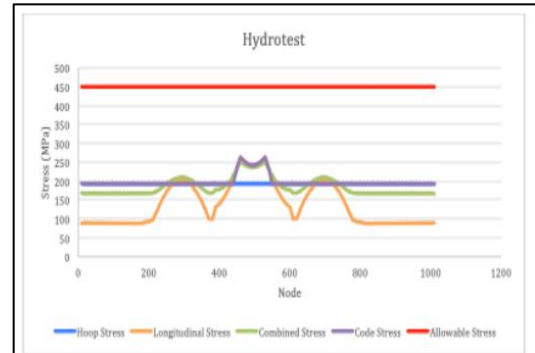


Figure 12. Stress graph for hydrotest

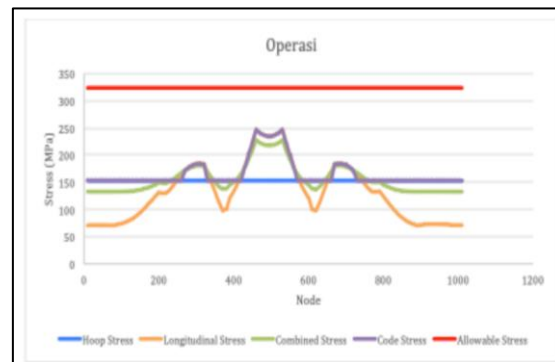


Figure 13. Voltage graph for operating conditions

The installation conditions do not have hoop stress because no internal pressure occurs. The maximum stress that occurs in installation conditions is 176.3 MPa. The maximum stress that occurs in hydro test conditions is 263.6 MPa. The maximum stress that occurs under operating conditions is 247.4 MPa. The maximum stress occurs at the highest crossing support because it produces significant buckling.

Based on research conducted by [1] and Ricky, the 4.5 km distribution pipe has a diameter of 6,625 inches. This underwater pipeline route must pass or cross with two existing pipelines. The crossing occurred at KP (Kilometer Point) 4,106 and 4,113, where KP 0 was on platform A, and KP 4.5 was on platform B. The free span length obtained was 7.5 m, and this value was used for crossing analysis. The height of the supporting structure also influences this analysis. The stress from the crossing analysis is checked to meet the permitted stress. Two models were designed: four concrete mattress structures with one concrete sleeper structure and seven concrete sleeper structures. Both models have met the requirements.

Jessica and Krisnaldi also researched the planned gas transmission route conditions from Muara Karang to Muara Tawar along 36.96 km using a reversible flow system. The gas transmission line is part of the PT project. PLN (PERSERO) named Subsea Gas Pipeline Transmission Project BojonegaraLNLG RTRF–Muara Karang PS–Muara Tawar PS. The gas transmission line area that will be reviewed is the area where there are Kilo Points 22.5 to Kilo Point 25. By analyzing the stress in the initial pipeline crossing design, the maximum stress value is obtained at 60.3% of the allowable stress at the support point. Therefore, the crossing pipeline design meets the requirements because the stress that occurs does not exceed the allowable stress. Based on the stress analysis that has been carried out, it can be concluded that the maximum stress always occurs at the support pipeline crossing.

3. Conclusion

Based on the analysis of crossing subsea pipelines, three criteria need to be met in order to realize crossing pipelines over existing pipes: The analysis of subsea crossing pipelines requires the fulfillment of three criteria, namely pipe thickness according to DNV-OS F101 standard, pipe stability according to DNV-RP F105 standard, and free span length according to DNV-RP F105 standard. The subsea crossing pipe must be designed with respect to the pipe wall thickness, pipe stability when placed underwater, and free span length in order to meet the permissible strength requirements. Analysis of subsea crossing pipes shows that the maximum stress always occurs at the support point of the pipe crossing. The design of the subsea crossing pipe must meet the strength requirements so that the stresses that occur do not exceed the allowable stresses. An installation analysis using the static S-Lay method is performed to determine the pipelay vessel configuration so that the pipe stresses that occur meet the allowable stresses. Subsea crossing pipelines must be designed with safety factors and resistance to environmental loads and system pressures in mind. The design of subsea crossing pipelines must consider factors such as pipeline wall thickness, pipeline stability, and free span length in order to meet the permissible strength requirements.

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