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Full paper

Local Buckling in End Expansion of Subsea Pipelines

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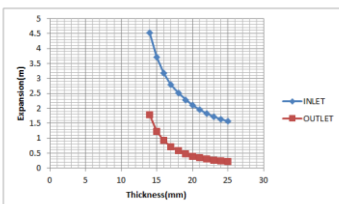
Graphical abstract



Abstract

Offshore pipeline is mainly to transport crude oil and gas from offshore to onshore. It is also used to transport crude oil and gas from well to offshore platform and from platform to another platform. The crude oil and gas horizontally flows on the seabed, and then vertically flows inside the riser to the offshore platform. One of current issues of the oil and gas transportation system is an end expansion caused by the axial force. If the end expansion occurs over it limit can cause overstress to riser. This paper explores the effect of axial force toward local buckling in end expansion. In the study, development of programming in visual basic 2010 firstly was constructed using empirical equation. The programming code, then, was validated by comparing simulation result with actual data from company. As case study, the end expansion for various thicknesses of pipes was simulated. In this programming, DNV regulation is included for checking either design complied or not with regulation. However, DNV regulation doesn't have specific rule regarding the end expansion but it is evaluated under load displacement control under strain condition.

Keywords: End expansion; external pressure; exponential; linear; uniform; DNV regulation

■1.0 INTRODUCTION

Demand on oil and gas industry has increase today and many of oil and gas company growth for exploration of oil and gas. During the last few decades, exploration of oil and gas shifts from onshore to offshore. Oil and gas are transported through LNG vessel and pipelines to the onshore. LNG has a higher operating cost where the initial cost of the pipeline is higher but operation cost is lower.

Today, pipelines are used to transport the oil and gas from offshore to onshore. In deep water, oil exploration, pipeline used to transport the oil and gas from oil well to the floating platform like FPSO. In order to construct the pipeline system, consideration should give on the route of the pipeline, seabed condition, and hydrodynamic behavior, wave current and human activity. Design of pipeline gives an attention on material grade used and thickness of pipelines. Material grade that used shall withstand with high temperature and high pressure, usually high material grade give higher cost and to minimize the cost, consideration on thickness of pipe for safety against external force. External pressure and Internal are used to determine the thickness of pipeline.

■2.0 LITERATURE REVIEW

Flowlines to high fluid temperature and pressure create high effective axial compressive force due to high fluid temperature and internal pressure. Pipeline system before operate undersea have to follow the installation, testing and finally can operate. During the installation, pipeline are twisted, bent and pulled. When its start its operation, pipeline will experienced external pressure from sea, internal pressure from fluid carried and external force that come from dropped object, fishing activity [3].

2.1 Pipe SMYS and SMTS

Table 1 shows the SMYS (Specific Minimum Yield Strength) and SMTS (Specific Minimum Tensile Strength) of pipeline based on the material grade. The higher the material greed is the higher value of minimum yield strength and a minimum tensile strength [2].

Table 1 Pipe SMYS and SMTS [2]

API Grade	SMYS MPa	SMTS Mpa
X42	289	413
X46	317	434
X52	358	455
X56	386	489
X60	413	517
X65	448	530
X70	482	565
X80	551	620

2.2 Displacement Controlled Condition

DNV regulation gives the formula for analyzing the local buckling. Using displacement controlled condition that gives the comparison between strains of DNV regulation and deign strain. Comparison between design and rule indicate the condition of pipeline either passed or not. In this formula, parameter used includes minimum internal pressure, external pressure, girth weld factor.

$$\varepsilon_{sd} \leq \varepsilon_{rd} = \frac{\varepsilon_{rd}(t_2, p_{min} - p_e)}{\gamma_\epsilon} \qquad (1)$$

where, $\varepsilon_{sd}$is design compressive strain

$$\varepsilon_{rd}(t_2, p_{min} - p_e) = 0.78\left(\frac{t}{D} - 0.01\right)\left(1 + 5.75\,\frac{p_{min} - p_e}{p_b(t)}\right)\alpha_h^{-1.5} a_{gw} \qquad (2)$$

p_{min}isminimum internal pressure and$p_e$is an external pressure,$p_e = \rho g h$.

$$\alpha_h = \left(\frac{R_{t,0.5}}{R_m}\right)_{max} \qquad (3)$$

$$\left(\frac{R_{t,0.5}}{R_m}\right)_{max} = 0.93 \qquad (4)$$

a_{gw}isgirth welds factor.

3.0 METHODOLOGY

This project starts by find the information about pipelines and offshore industry as shown in Figure 1. Pipeline and offshore industry were closed related since transportation of oil and gas are using pipelines Information of pipelines and problem relates to this topic are obtained by searching the past journal and select that relates to effective axial force toward pipeline. Literature review had done by searching the journal that has a case with the theory. Theory for effective axial force and its effect to local buckling are determined. Theory only focuses local buckling and only collects the formula and information that relate to this theory. Scope of research had narrow to the effect of axial force toward end expansion. Refer to regulation of DNV on Submarine Pipeline to follow the criteria of this classification society. All calculation and formula follow the regulation of DNV. In the DNV regulation, there is no formula that specific to end expansion. To achieve the objective, formula displacement control is used. In this formula, axial force are express in the form of strain. The formula used in the theory need the data to be calculated.

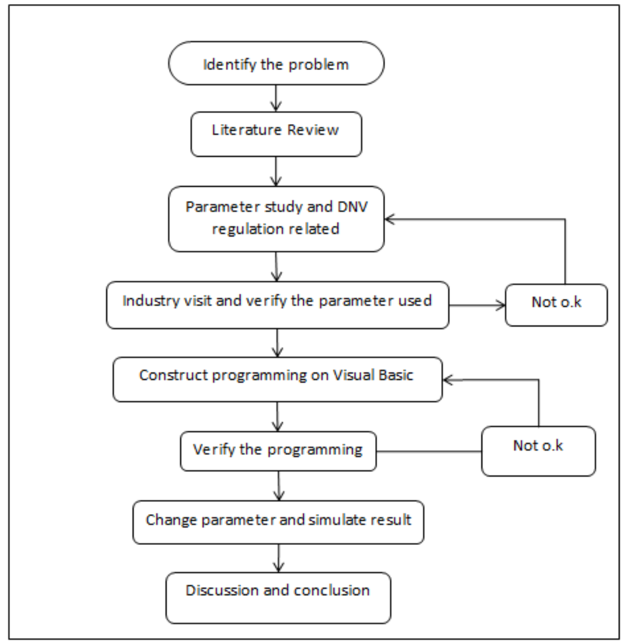


Figure 1 Process flow of research

Industrial visit is made after the presentation 1 to collect data and learn how to use software and analyze the data. The process of searching data to be used in the theory may obtain from the company but that data are confidential. Programming constructs using visual basic based on the formula collected .This simple programming combined the empirical formula that used in determining the end expansion. In this programming also was included the formula by DNV regulation to compare the design value with regulation value. From the result obtain, comment and discussion are given relating to the topic and some recommendation based on analysis.

4.0 PRINCIPLE THEORY

4.1 Force

a) Pressure Force Expansion

$$F_{P1} = PA_i\left[1 - \frac{2\upsilon(D-t)}{(D-2t)}\right] \qquad (5)$$

b) Friction Force

$$F_{F1} = fW_S x_1 \qquad (6)$$

4.2 Exponential Temperature End Expansion Theory

a) Thermal Expansion Force

$$F_{T1} = EA_S\alpha\Delta T(x_1) \qquad (7)$$

$$\Delta T(x_1) = \Delta T_1 \exp\left(-\frac{x_1}{\lambda}\right) \qquad (8)$$

Combine equation, thermal expansion force becomes:

$$F_{T1} = EA_S\alpha\Delta T_1 \exp\left(-\frac{x_1}{\lambda}\right) \qquad (9)$$

b) Anchor length(long pipe)

$$PA_i\left[1-\frac{2\upsilon(D-t)}{(D-2t)}\right]+EA_S\alpha\Delta T_2\exp\left(\frac{L_{A2}}{\lambda}\right)=fW_SL_{A2} \quad (10)$$

c) Anchor length (short pipe)

$$L_{A1}=(EA_S\alpha\left[\Delta T_1\exp\left(\frac{-L_{A1}}{\lambda}\right)-\Delta T_2\exp\left\{\frac{L_T-L_{A1}}{\lambda}\right\}\right]+fW_SL_T)/(2fW_s) \quad (11)$$

d) Expansion

$$\Delta L_1=\frac{L_{A1}}{EA_S}\left(F_{P1}-\frac{fW_SL_{A1}}{2}\right)+\alpha\lambda\Delta T_1\left[1-\exp\left(-\frac{L_{A1}}{\lambda}\right)\right] \quad (12)$$

4.3 Linear Temperature End Expansion Theory

a) Thermal Expansion Force (F_{T1}):

$$F_{T1}=EA_S\alpha\Delta T_1+EA_S\alpha M_1L_{A1} \quad (13)$$

b) Anchor length (long pipe)

$$L_{A1}=\frac{PA_i\left[1-\frac{2v(D-t)}{(D-2t)}\right]+EA_S\alpha\Delta T_1}{fW_s-EA_s\alpha M_1} \quad (14)$$

c) Anchor length (short pipe)

$$(2L_{A1}-L_T)=\frac{EA_S\alpha(\Delta T_1-\Delta T_2)}{fW_S-EA_S\alpha M_1} \quad (15)$$

d) End expansion

$$\Delta L_1=\frac{L_{A1}}{EA_S}\left[F_{P1}+EA_S\alpha\Delta T_1+\frac{L_{A1}}{2}(EA_S\alpha M_1-fW_S)\right] \quad (16)$$

4.4 Uniform Temperature End Expansion Theory

a) Thermal expansion force

$$F_T=EA_S\alpha\Delta T \quad (17)$$

b) Anchor length (long pipe)

$$L_A=\frac{\left[PA_i\left[1-\frac{2v(D-t)}{(D-2t)}\right]+EA_S\alpha\Delta T\right]}{(fW_s)} \quad (18)$$

c) Anchor length (short pipe)

$$L_A=\frac{L_T}{2} \quad (19)$$

d) End Expansion

$$\Delta L=\frac{L_A}{EA_S}\left[F_P+EA_S\alpha\Delta T-\frac{fW_SL_A}{2}\right] \quad (20)$$

4.5 Burst Pressure

$$p_l=0.5(SMTS+SMYS)\frac{2t}{D} \quad (21)$$

4.6 Hoop Stress

$$\sigma_h=(p_i-p_e)\frac{D_o-t}{2t} \quad (22)$$

5.0 SIMULATION AND DISCUSSION

5.1 Programming Flowchart

In the simulation, three temperature conditions are taken into account which is exponential, linear and uniform as shown in Figure 2.

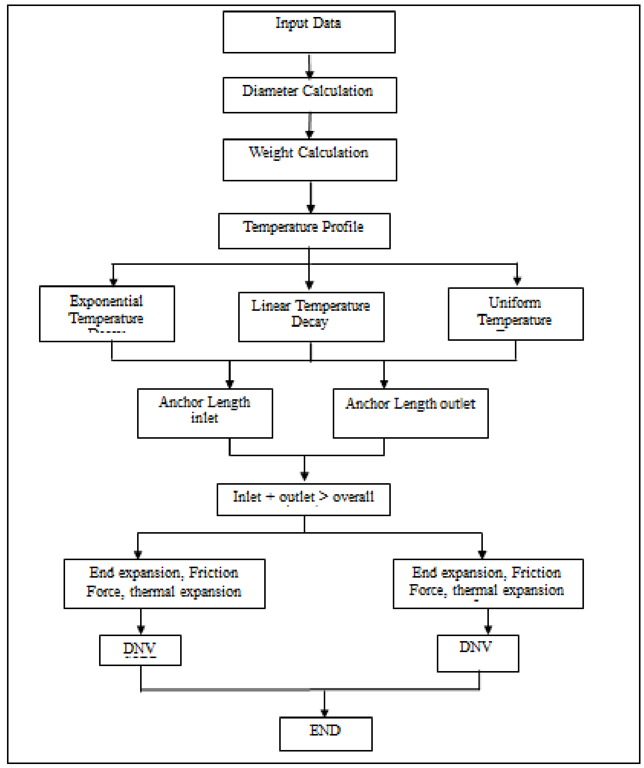


Figure 2 Flowchart of simulation

5.2 Data Collected

Table 2 and Table 3 and Table 4 show data of pipe and environmental and operational conditions which were used in the simulation.

Table 2 Detailed of pipe data used in the simulation

PIPE DATA	
Outside Diameter (mm)	762
Corrosion Coating Thickness (mm)	5
Concrete Coating Thickness (mm)	40
Pipe Density (kg/m^3)	7850
Corrosion Coating Density (kg/m^3)	1280
Concrete Coating Density (kg/m^3)	3040
Young modulus	2.07x10^11
Thermal Coefficient	1.17x10^-5
Poisson Ratio	0.3
Overall pipeline length (m)	27.00

Table 3 Environmental conditions as input data

Environmental Condition	
Seawater density	1025 kg/m^3
Friction Factor	0.4
Min seabed temperature	21 C^o

Table 4 Operational conditions used in the simulation

Operating Condition	
Internal pressure	9.38 Mpa
Outlet temperature	27 C^o
Inlet temperature	55 C^o

6.0 RESULTS AND DISCUSSION

Simulation was carried out using Subsea Pipeline and Flow Assurance Software by Ocean and Aerospace Research Institute, Indonesia as shown in Figure 3.

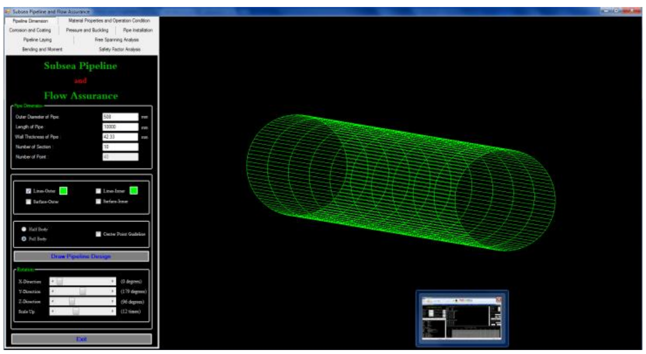


Figure 3 Subsea pipeline and flow assurance software

The following result in Table 5 shows the comparison of the result between the programming result and data from companies.The data from company and programming are ranged up to four decimal places. Condition for exponential temperature in long pipe case at outlet, linear temperature short pipe at inlet, uniform temperature for long pipe and short pipe at both outlet and inlet showed the different value. This maximum different value is only 0.0001 m or 0.02 percent from actual value. This different is because of decimal places that are round off to the nearest value. Based on the programming construct based on theory of end expansion, the result obtained as shown in Table 6 and Figure 4. Programming builds give out the result of end expansion, pipeline condition, empirical strain and DNV strain. Based on the result of end expansion against thickness, its a show that inlet region have greater expansion compare to outlet. This program identifies the limit of pipeline to pass the DNV regulation. Criteria have tested by this programming to comply with DNV regulation by measure the value of burst pressure and strain. In DNV regulation, there is no specific formula for calculation of end expansion. So to comply with the DNV regulation, under load displacement controlled section using the formula of strain to test either design strain are complying or not. To pass the DNV regulation, designed strain should be lower than rule strain. In the design of pipeline, strain is not the serious problem to comply with DNV regulation but it can affect to fixed riser fatigue. Serious issue in DNV regulation is burst pressure where it indicates the limit of pipeline to withstand high pressure. This programming setting is the burst pressure to identify whether pipeline pass or failed. Burst pressure from DNV regulation will be compared with designing operating pressure.

Comparing empirical formula and DNV regulation in this programming showed that empirical formula only used the general data on carbon steel. In DNV there are specific grade material value like specific minimum yield strength (SMYS) and specific minimum tensile strength(SMTS) where by changing of this material will result in changing of strain and burst pressure.

Table 5 Comparison between simulation results and company data

Pipeline Case	End Expansion Programming Result		End Expansion Company Result	
	Inlet(m)	Outlet(m)	Inlet(m)	Outlet(m)
Exponential temperature - long pipe	2.2781	0.4801	2.2781	0.4802
Exponential temperature - short pipe	0.1403	0.0465	0.1403	0.0465
Linear temperature - long pipe	0.4126	0.0558	0.4126	0.0558
Linear temperature - short pipe	0.6014	0.1324	0.6015	0.1324
Uniform temperature - long pipe	0.1859	0.1859	0.1860	0.1860
Uniform temperature - short pipe	0.8144	0.8144	0.8145	0.8145

Table 6 Result varying thickness with end expansion

Thickness(mm)	Inlet Expansion(m)	Outlet Expansion(m)
14	4.52	1.79
15	3.72	1.23
16	3.19	0.92
17	2.80	0.72
18	2.51	0.58
19	2.29	0.48
20	2.10	0.40
21	1.96	0.35
22	1.83	0.31
23	1.73	0.27
24	1.64	0.24
25	1.56	0.21

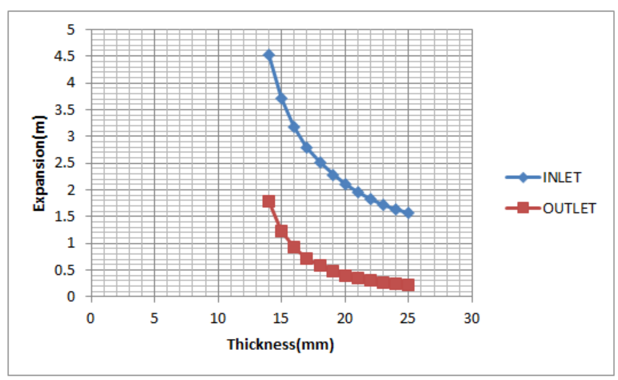


Figure 4 Result plotted of end expansion against thickness

7.0 CONCLUSION

This paper identifies the limit of pipeline to pass the DNV regulation. Criteria have tested by this programming to comply with DNV regulation by measure the value of burst pressure and strain. In DNV regulation, there is no specific formula for calculation of end expansion. So to comply with the DNV regulation, under load displacement controlled section using the formula of strain to test either design strain are complying or not. To pass the DNV regulation, designed strain should be lower than rule strain. In the design of pipeline, strain is not the serious problem to comply with DNV regulation but it can affect to fixed riser fatigue. Serious issue in DNV regulation is burst pressure where it indicates the limit of pipeline to withstand high pressure. This programming setting is the burst pressure to identify whether pipeline pass or failed. Burst pressure from DNV regulation will be compared with designing operating pressure.

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Acknowledgement

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