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Damage Analysis of Subsea Pipeline Due to Anchor Drag

Ricky Lukman Tawekal[1*], Richo Prayudha Rante Allo[1] and Akhmad Taufik[2]

[1]Ocean Engineering Program – Institut Teknologi Bandung, Indonesia.
[2]Metallurgical Engineering Graduate Program – Institut Teknologi Bandung, Indonesia.

Abstract

Subsea pipelines are at risk of suffering damage because of third-party activities such as anchor drop and anchor drag. In this study, analysis of damage to subsea pipelines due to anchor drag was conducted using ABAQUS software. The pipeline located in Madura Strait was considered for the study, and hence the analysis was performed using the data of three types of large ships that pass through the Madura Strait. Global and local analyses were performed to calculate the maximum displacement, stresses, and strains that occur in the pipeline because of anchor drag. First, global analysis was performed to determine the maximum deflection of the pipeline using a model with line elements, and local analysis was then performed to determine the stresses and strains in the dented pipeline based on the conditions obtained from the global analysis. The integrity of the dented pipeline was finally determined based on ASME 31.8 and DNV OS F101 standards.

Keywords: Subsea pipeline, Anchor drag, Strain-based design.

INTRODUCTION

Pipelines in shipping lanes face high risk of damage because of anchor drag. Thus far, stress-based analysis has been used as the basis to determine the integrity of the pipelines; when the stress in the pipe exceeds the yield stress, the pipe has to be repaired. Repairs conducted outside the maintenance schedule will cause losses, because the activities related to the pipeline, such as production and distribution, will have to be halted during the repairs. In this study, an analysis is conducted based on strain-based criteria for the case of subsea pipelines damaged by anchor drag in Madura Strait, to obtain the optimum integrity of the pipelines. Strain-based analysis can minimize the losses due to the repairs of pipelines performed outside the maintenance schedule.

METHODOLOGY

The methodology used in the strain-based analysis can be seen in **Figure 1**; the steps are as follows.

a. Collection of data of ships, metocean, and pipelines.
b. Analysis of global displacement due to the ships' anchor drag using line elements.
c. Analysis of local deformation using solid elements.
d. Determination of integrity of the dented pipeline based on ASME 31.8 and DNV OS F101 standards.

Strain-based design is a methodology of design that focuses on the strain limit together with the stress limit. The theory of strain is based on geometrical concepts of displacement and rotations. To relate the strain at a particular point to stress, material properties are required.

The appropriate stress-strain relationship and coefficients can be used to analyze the deformation and displacement of the structure, and predict the inelastic or plastic response of the material.

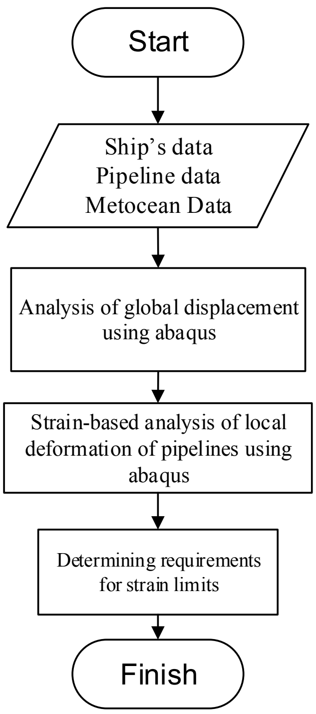


Figure 1: Flowchart of methodology for strain-based analysis

As per ASME B31.8, the allowable depth of dents is 6% of the diameter of the pipeline, whereas, as per DNV OS F101, the limit is set at a strain value of 5%.

ANALYSIS AND RESULT

In this study, the case of an anchor drag on the submarine pipelines in Madura Strait, Indonesia is analyzed. Analysis is conducted to obtain the global displacement due to the ships' anchor drag using line elements and also the local deformations at the point of contact between the pipeline and the ships' anchors using solid elements. The location where the contact occurred was at the infield joint. In the analysis, three variables pertaining to the anchor drags of different ships are used. These three variables are based on the types of ships sailing through the Strait of Madura, and the ship having the largest size in each type of ship was considered for the analysis. The stress-strain properties of the material used in the analysis is shown in Figure 2.

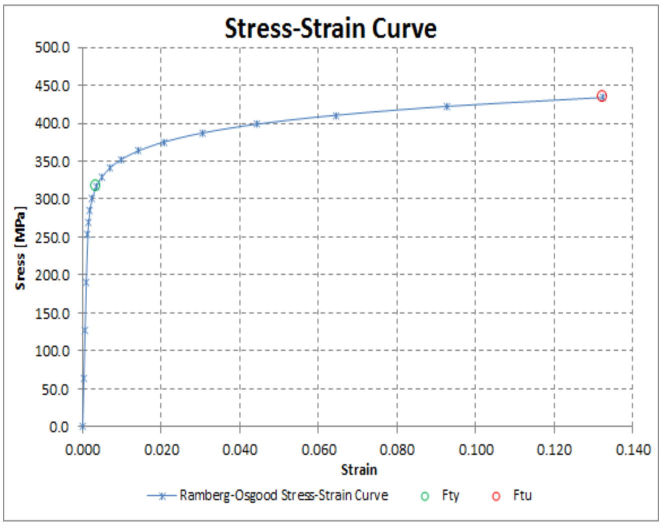


Figure 2:. Stress-strain curve of material API5L X46 based on Ramberg–Osgood method

Analysis of the Ships' Anchor Drag

The aim of global analysis is to obtain the maximum displacement of the pipelines due to the anchor drag, while the aim of local analysis is to obtain the local deformation (dent) of the pipelines due to the ships' anchor drag. The following assumptions are made in model used in the analysis of anchor drag using Abaqus.

- The seabed is assumed to be flat.
- The pipelines are straight.
- The land is not deformed, and embedment does not occur.
- The pipelines have the same dimensions along the span.
- The soil along the route of the pipelines is of the same type, i.e., clay with a lateral friction of 0.3.
- Both ends of the pipelines are free.

The model of the pipelines is shown in **Figure 3**.

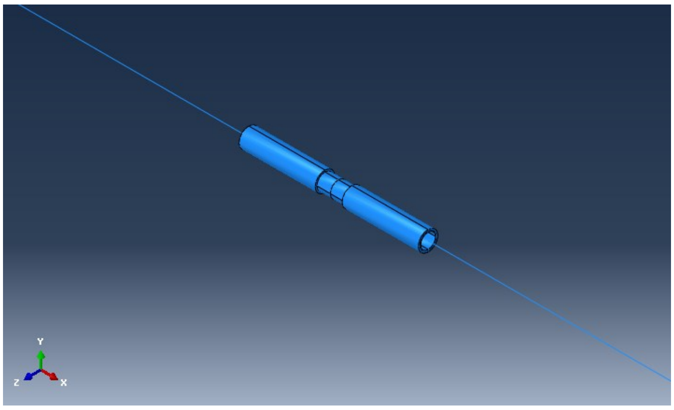


Figure 3: Modeling of pipelines in Abaqus

Global Analysis

Global analysis using line elements was conducted to obtain the maximum displacement due to the anchor drag. The result of the analysis is presented in **Table 1,** and the maximum displacement due to the anchor drag of the ship Sumatera Express is shown in **Figure 4**.

Table 1. Displacement values and lengths of pipelines dragged by ships' anchor

Name of Ship	Sumatera Express (Cargo ship)		CALIDA (Oil tanker)		MS Rotterdam (Passenger ship)	
Type of anchor	U43		U47		U41	
Speed of ships	6.482	m/s	7.357	m/s	9.054	m/s
Weight of anchor	11113	kg	13517	kg	9888	kg
Max drag force	4825	kN	5844.8	kN	4501.3	kN
Lateral displacement at center of spans (*strain 5%*)	9.369	m	9.2054	m	9.0948	m
Lateral displacement at center of spans (*dent 6%*)	15.21	m	15.068	m	15.499	m
Lateral displacement at center of spans (maximum)	213.062	m	318.369	m	183.8	m
Affected length (*strain 5%*)	862	m	502	m	866	m
Affected length (*dent 6%*)	1022	m	1030	m	1008	m
Affected length (maximum)	3396	m	4246	m	3116	m

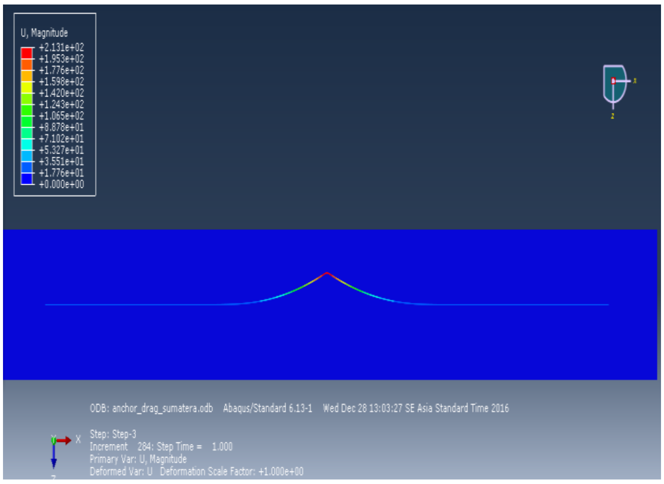


Figure 4: Maximum displacement due to anchor drag of Sumatera Express (4825 kN)

The graph of forces acting on the pipelines versus the displacements due to the anchor drag of the ship Sumatera Express are shown in Figure 5.

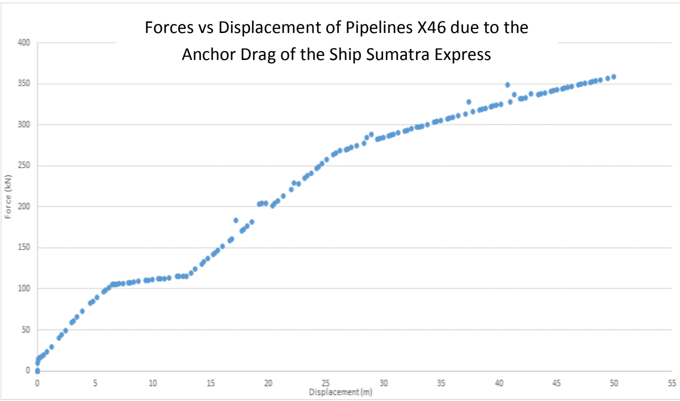


Figure 5: Graph of forces vs. displacement of pipeline due to anchor drag of Sumatera Express

Local Analysis

Local analysis was conducted to determine the depth of the dent, values of strain, and values of stress based on the standards DNV OS F101 and ASME B31.8, and the condition of maximum displacement. The result of the local analysis is presented in Table 2.

Table 2. Result of local analysis

Parameter		Ships		
		Sumatera Express	MS Rotterdam	Calida
DNV OS F101	Stress (MPa)	404.961	403.261	403.933
	Strain	5.28%	4.98%	5.10%
	Dent (mm)	9.69	9.17	9.38
	% dent	2.725%	2.579%	2.638%
ASME B31.8	Stress (MPa)	429.435	430.882	429.747
	Strain	11.497%	11.99%	11.604%
	Dent (mm)	20.9	21.7	21
	% dent	5.88%	6.102%	5.906%
Maximum Displacement	Stress (MPa)	434	434	434
	Strain	24.57%	24.06%	26.60%
	Dent (mm)	152	143	175
	% dent	42.745%	40.214%	49.213%

Based on percentage values of dent and the values of stress, the graph of the relation between stress and percentage of dent based on ASME B31.8 is shown in Figure 6.

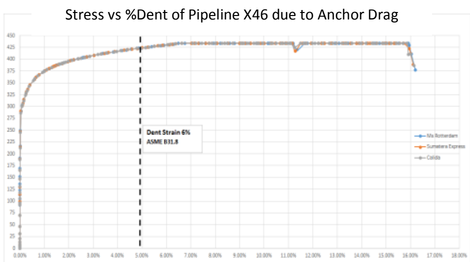


Figure 6: Graph of stress vs. % dent of pipelines X46 for the three ships

As per ASME B31.8, the allowable depth of the dents is 6% of the diameter of the pipeline. The graph shows that for the condition corresponding to 6% dent, the stress value in the case of the ship Sumatera Express is 431.002 MPa; the corresponding stress values in the case of the ship Rotterdam and the ship Calida are 430.882 MPa, and 430.483 MPa, respectively. Analysis based on the standard DNV OS F101 was conducted, and the graph showing the relationship between the values of stress and strain was plotted. The graph is shown in Figure 7; the limit of 5% for the strain value is also shown in the figure.

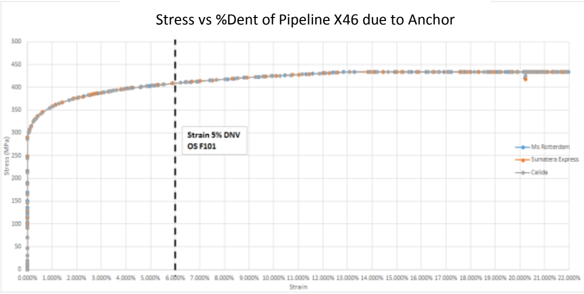


Figure 7: Graph of stress vs. strain in pipeline X46 due to ships' anchor drag

To observe the condition when a dent occurs as per this analysis, the graphs showing the relationship between the percentage of dent and displacement of the pipelines was plotted; these graphs are shown in Figures 8 to 10.

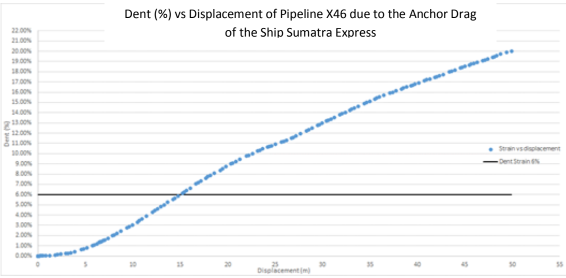


Figure 8: Dent (%) vs. displacement of pipeline X46 due to anchor drag of the ship Sumatera Express

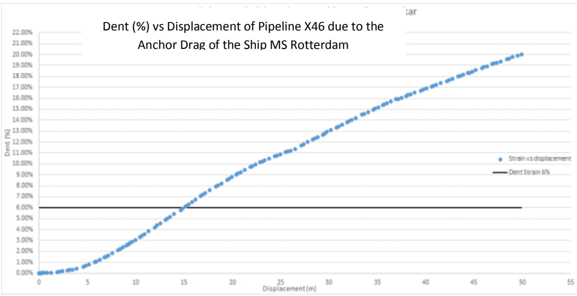


Figure 9: Dent (%) vs. displacement of pipeline X46 due to anchor drag of the ship MS Rotterdam

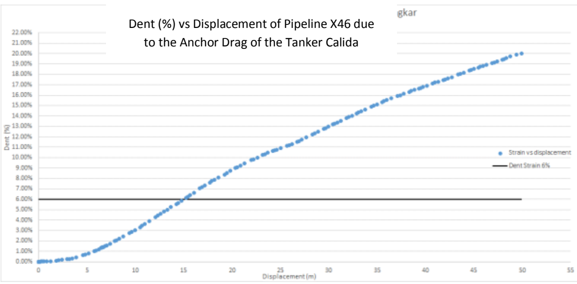


Figure 10: Dent (%) vs. displacement of pipeline X46 due to anchor drag of the tanker Calida

Figure 8 shows that the dent of 6% depth had occurred before the pipeline reached its maximum displacement. The graph also shows that local deformation (dent) occurred on the pipeline since the beginning of the impact between the ship's anchor and the surface of the pipeline. The local deformation at the time of occurrence of the dent in the case of the ship Sumatera Express is shown in Figures 11 to 13.

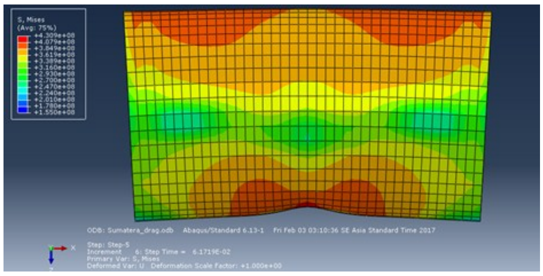


Figure 11: Deformation at 6% dent condition (Zoom, Sumatera Express) as seen from above

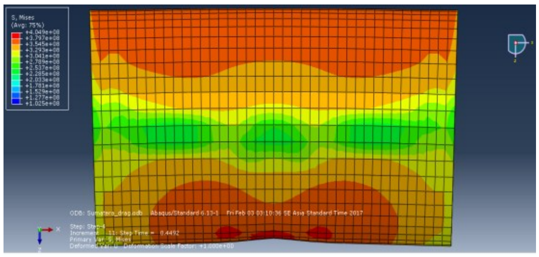


Figure 12: Deformation at 5% dent condition (Zoom, Sumatera Express) as seen from above

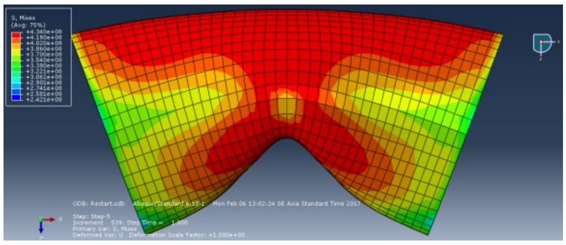


Figure 13: Deformation at maximum displacement condition (Zoom, Sumatera Express) as seen from above

The result of analysis shows that the limit of 6% for the dent (based on ASME B31.8) occurs in the pipelines at a stress value of ± 430 MPa or 99.078% SMTS, and that the strain limit of 5% (based on DNV OS F101) occurs at a stress value of ± 404 MPa or 93,088% SMTS. The graphs of the maximum stress with each ship's anchor drag are shown in Figures 14 to 16.

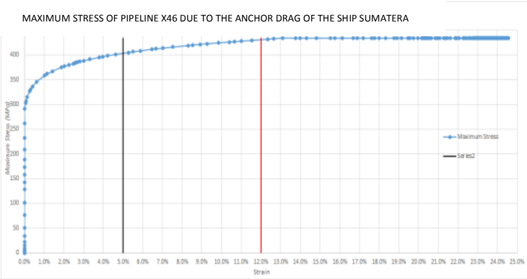


Figure 14: Maximum stress in pipeline X46 due to anchor drag of the ship Sumatera Express

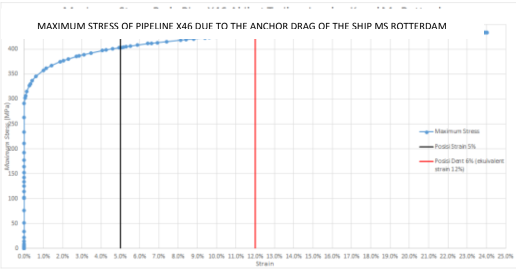
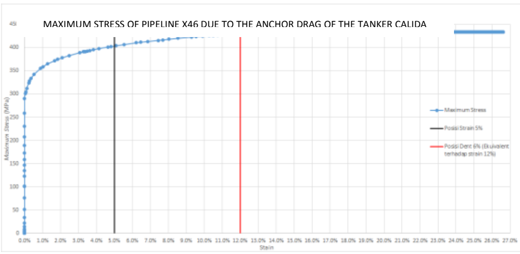


Figure 15: Maximum stress in pipeline X46 due to anchor drag of the ship MS Rotterdam



Figures 16: Maximum stress in pipeline X46 due to anchor drag of the tanker Calida

Based on the maximum stress in the case of each ship, we find that for the ship Sumatera Express, the value of maximum stress occurring at the strain of 5% is 404.961 MPa, while at the condition of 6% limit for the dent, it is 429.435 MPa; for the ship MS Rotterdam, the value of maximum stress occurring at the strain of 5% is 403.261 MPa, while at the condition of 6% limit for the dent, it is 430.882 MPa; for the tanker Calida, the value of maximum stress occurring at the strain of 5% is 403.933 MPa, while at the condition of 6% limit for the dent, it is 429.747 MPa. In the above conditions, the stress value at the other points does not exceed the stress value occurring at the point where the anchor drag occurs.

CONCLUSION AND RECOMMENDATION

The integrity of a pipeline damaged due to anchor drag can be determined using strain-based criteria. It was shown that optimum results can be obtained using strain-based criteria.

Some suggestions for further research on the analysis of damage to pipelines due to ships' anchor drag are given below.

1. Global analysis needs to consider the bathymetric data of the region where the pipeline is located, and also the angle of the ships' anchor drag, so that the actual condition is simulated.
2. In the local analysis of the ships' anchor drag, the depth of the dent in the pipelines can increase without resulting in crack, and hence further analysis needs to be done regarding initiation of cracks.

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