Analysis of the Effect of Using Concrete Mattresses on Subsea Pipelines

*Risal[1], Juswan Sade[2] Fuad Mahfud Assidiq[3]

Department of Ocean Engineering, Faculty of Engineering, Hasanuddin University, Indonesia
*Correspondence author: : Risal3559@gmail.com ; Tel.: +6289629986928

A b s t r a c t

This Leaks in oil and gas pipes under the sea will cause pollution and threaten the ecosystem in the sea. Damage to underwater pipes caused by anchors has quite a large percentage, therefore good prevention efforts are needed so that leaks do not occur which have a negative impact on environment and economy. The aim of this research is to find out how the strength compares between pipes that use protective concrete mattresses and pipes without protective concrete mattresses when hit by ship anchors. This research uses explicit dynamic simulation using Finite Element Method software. Based on explicit dynamic analysis, deformation values and equivalent stress values are obtained after being hit by an anchor at a speed of 5,491 m/s. For unprotected pipes experiencing significant damage, when viewed from the deformation values obtained, namely amounted to 0.143 m, while for the pipe model with protection the deformation value obtained was 0.0769 m. For pipes without protection and pipes that use protection with a thickness of 0.15 m, the deformation value is both above the maximum value that has been determined, namely 10% of the diameter value and when viewed from the equivalent stress value, for pipes without protection the equivalent stress value is obtained. namely 1,150 MPa, while the pipe that uses a protector is 240 MPa, the equivalent stress value obtained by the pipe using a protector is below 780 MPa, which means that the use of pipe protectors is quite effective in reducing damage that occurs to the pipe.

Keywords: Concrete Mattresses; Deformation; Equivalent Stress, Explicit Dynamic

1. Introduction

Indonesia is a country that has very large and abundant natural gas reserves, making Indonesia one of the countries with the largest natural gas reserves in the world. The future and potential of natural gas reserves in Indonesia have an important position in the progress of the energy transition. This cannot be separated from the fact that as much as 88% of energy needs in Indonesia are still supplied from conventional energy sources such as coal and natural gas (Mahendra et al., 2022). Natural gas is an energy source that comes from fossilized plants, animals, and microorganisms that have been stored underground for thousands or even millions of years. As one of the countries with the largest natural gas reserves, Indonesia contributes to meeting 1.5% of world gas reserves. Indonesia itself has many natural gas-producing areas such as Arun, which is an area located in Aceh, Bontang which is in Kalimantan, and Tangguh which is in Papua and Natuna Island. In everyday life, many benefits can be taken from natural gas, including as fuel for industry, households, vehicle fuel, and as an electricity generator. The petroleum production process itself is divided into 2 important stages, the first stage is exploration, where this stage is to obtain information about areas that have petroleum reserves, and then the exploitation stage, which is related to oil production. These activities include drilling and completing wells, transportation for oil separation and refining, and storage and construction of processing facilities.

The use of piping systems in the oil and gas industry as a means of distributing oil and gas products is very effective and efficient, especially over long distances compared to using land or air routes. Judging from the very diverse routes that pipes take, potential dangers and safety risks such as leaks, spills, explosions, and environmental pollution may occur (Martaningtyas & Ariesyady, 2018). Oil and gas pipeline leaks under the sea will cause pollution and threaten marine ecosystems, such as fish and coral reefs. This will also have an impact on the economy of people who depend on marine products for their livelihoods. Pollution can cause many fish to die so fishermen's catches will decrease. Therefore, good prevention efforts are needed to prevent pipe leaks from occurring which hurt the environment and the economy.
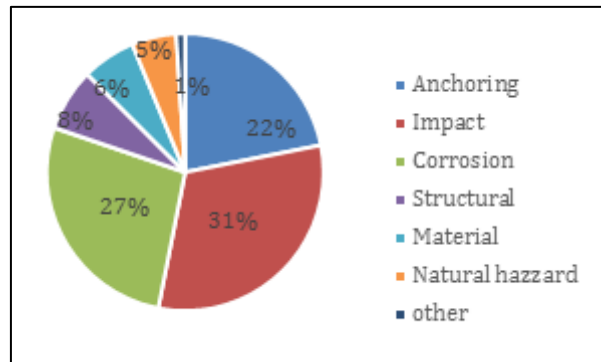

Figure 1. Causes of damage to underwater pipes

In the picture above, it can be seen that damage to pipes caused by ship anchors has a fairly large percentage. Based on this, research was carried out as an effort to prevent underwater pipe leaks.

Subsea pipelines used in the oil and gas industry are vital infrastructure that is vulnerable to various risks, including damage due to impacts from ship anchors. Damage to underwater pipelines can not only cause environmental pollution and threats to marine ecosystems, but also impact the economies of communities that depend on marine resources. Therefore, effective prevention efforts are needed to prevent pipe leaks which can be detrimental to the environment and the economy.

One method used to protect underwater pipes from damage due to anchor impacts is the use of concrete protectors, such as concrete mattresses. This research aims to evaluate how effective the use of concrete mattresses is in protecting underwater pipes when they are hit by ship anchors. By using explicit dynamic simulation with the finite element method, deformation analysis and equivalent stress values are obtained after the pipe is hit by an anchor impact at a certain speed.

In the context of Indonesia, which is one of the countries with the largest natural gas reserves in the world, protecting undersea pipeline infrastructure is very important considering Indonesia's large contribution to meeting global energy needs. Thus, it is hoped that this research will provide valuable insight into the effectiveness of using concrete mattresses as a method of protecting underwater pipes in anchor impact scenarios.

With this background, this research was conducted at the Offshore Building and Underwater Work Production Management Laboratory, Faculty of Engineering, Hasanuddin University. The data used includes pipe property data, ship data, anchor data, location depth data, and data regarding concrete mattresses. Through this research, it is hoped that a deeper understanding can be gained about the protection of underwater pipes and the contribution of concrete mattresses in reducing the risk of damage due to anchor impacts.

2. Materials and Methods

This research was conducted at the Offshore Building Production Management and

Underwater Work Laboratory, Faculty of Engineering and Hasanuddin University.
The data used in this research are:
1. Pipe property data
2. Ship data
3. Anchor data
4. Location depth data
5. Data on concrete mattresses
3. Results and Discussion

Table 1. Pipe Property Data

Parameter	Value	Unit
Pipeline Length	13.5	km
Outer Pipe Diameter	16	inch
Pipe Wall Thickness	1.574	inch
Material Specification	Carbon Steel	-
Material Grade	API 5L Grade X60 MO PSL2CS	-
Pressure	710	psi
SMYS (Specified Minimum Yield Strength)	78×10^7	N/m^2

Table 2. Ship data

Vessel Name	RT Leo
Vessel Type	Bulk Carrier
Gross Tonnage (GT)	34,043
Deadweight Tonnage (DWT)	53,776
Length Overall (LOA)	194 m
Length Between Perpendiculars (LBP)	184.3 m

Table 3. Anchor data

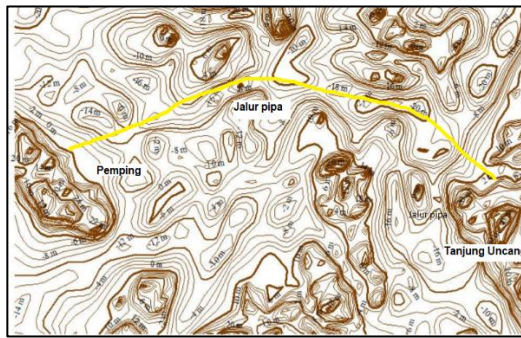| Parameter	Value	Unit
Length	2.108	m
Width	2.275	m
Weight	8,700	kg
Volume	1.108	m³
Anchor Area	4.795	m²

Figure 2. Bathymetric map of the Tanjung Uncang pipeline installation in Batam

In this study, a protector with a thickness of 0.15 m was used with a weight of 608.5 kg
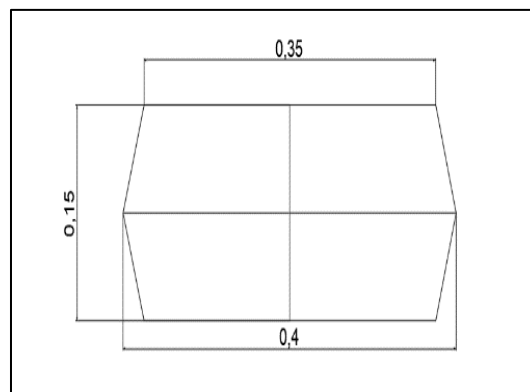

Figure 3. Pipe protection model

3. Result

3.1. Analysis of the calculation of impact energy on the anchor when it is dropped

Table 4. Parameters used in determining terminal speed

No	Parameter	Value	Unit
1	Object Mass	8,700	kg
2	Gravitational Acceleration	9.8	m/s²
3	Object Volume	1.1083	m³
4	Seawater Density	1,025	kg/m³
5	Drag Coefficient	1	-
6	Anchor Area	4.7957	m²

The anchor speed is calculated using the equation :

$$V_T = \sqrt{\frac{2\,(m-V.\rho).g}{\rho.CD.A}}$$

$$V_T = \sqrt{\frac{2\,(8700 - 1,1083\ x\ 1025)9,8}{1025\ x\ 1\ x\ 4,7957}}$$

V_T = 5,491 m/s

After calculating the speed of the falling anchor, then calculate the impact energy using the equation:

$$E_E = \frac{1}{2}\,(m + ma\,).\,V_T{}^2$$

$$E_E = \frac{1}{2}\,(8700 + 5629,107\,)\ x\ 30,16$$

$$= 216082,9 \text{ Joule}$$

$$= 216,08 \text{ KJ}$$

Where :

m = Mass of object (kg)

g = Acceleration due to gravity (9.81 m/s2)

V = Volume of object (m3)

ρ = Density of sea water (1025 kg/m3)

CD = Drag coefficient

A = Projected area of the object (m2)

VT = Terminal speed (m/s)

EE = Energy impact (J)

ma = added mass (kg)

ma= ρ. Ca.v

Ca = mass coefficient value

3.2. Pipe protection modeling using Rhinoceroz software
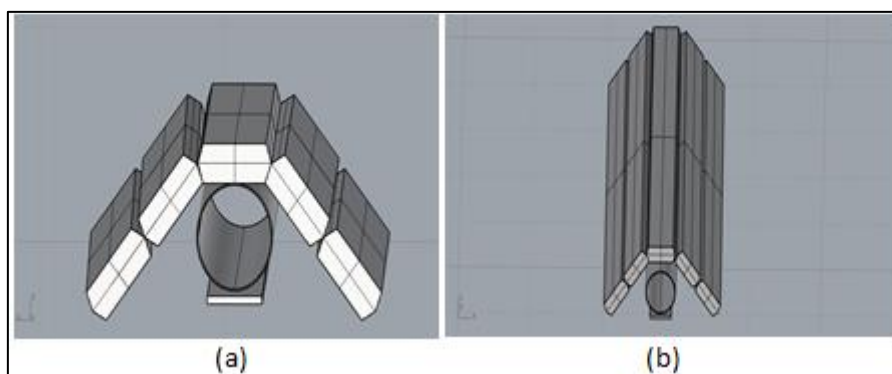

Figure 4. Pipe protection model (a). Front view (b). Top view

3.3. Analysis of deformation in pipes

The amount of damage or deformation value that occurs in the pipe caused by the anchor when it falls is greatly influenced by the impact energy that occurs when the anchor hits the pipe which can be calculated using the equation:

$$\delta = \left(\frac{E \cdot 9^{1/2} \cdot t^{1/2}}{16 \cdot (2\pi)^{\frac{1}{2}} \cdot mp \cdot D^{3/2}}\right)^{2/3} \cdot D$$

$$\delta = \left(\frac{216082,91 \; x \; 3 \; x \; 0,2}{16 \; x \; 2,505 \; x \; 31200 \; x \; 0,259}\right)^{2/3} x \; 0,40$$

$$\delta = 0,158 \; m$$

Where :
δ = depth of pipe dent / dent (m)
E= Impact or collision energy (J)
t = Pipe wall thickness (m)
σ_y= Yield stress (N/m2)
m_p= Pipe wall moment
(1/4 x σ_yx t2)
D = Outside diameter of the pipe (m)

    The pipe that passes through the area around the Tanjung Uncang shipyard with a pipe diameter of 0.40 m, when hit by an anchor weighing 8700 kg, based on the analysis results, the value of deformation or damage that occurred to the pipe was 0.158 m.

3.4. Analysis using ANSYS software

    The steps taken in explicit dynamic analysis using ANSYS software are as follows,

1. Export the model created using rhinoceros to ANSYS geometry
2. Arrange the materials that will be used in the engineering data. For this explicit dynamic simulation, 3 materials are used, namely structural steel, carbon steel and concrete.
3. Carrying out meshing, meshing or griding is the process of dividing the components to be analyzed into small or discrete elements. So the model becomes 8203 parts after meshing.
4. Set the velocity and fixed support for the model to be simulated.
5. The next stage is solution, in this stage look for deformation and equivalent stress in the simulated model.

The deformation and equivalent stress values obtained using ANSYS are as follows:
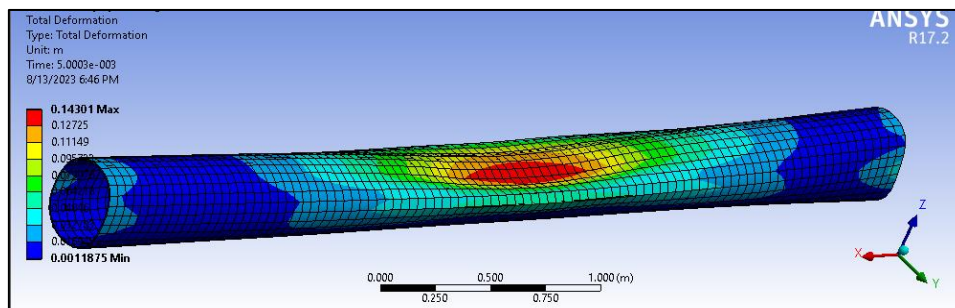

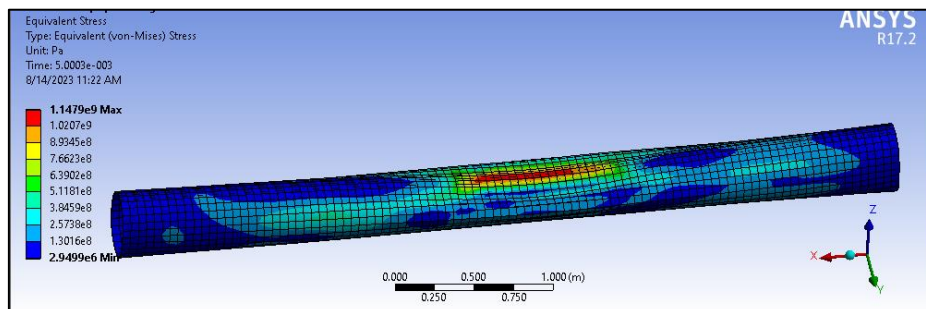**Figure 5.** Deformation values in unprotected pipes

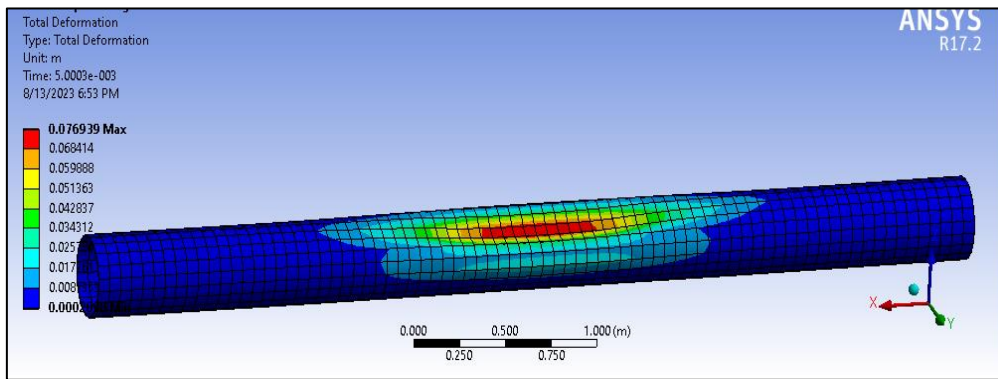**Figure 6.** Equivalent stress value for unprotected pipes

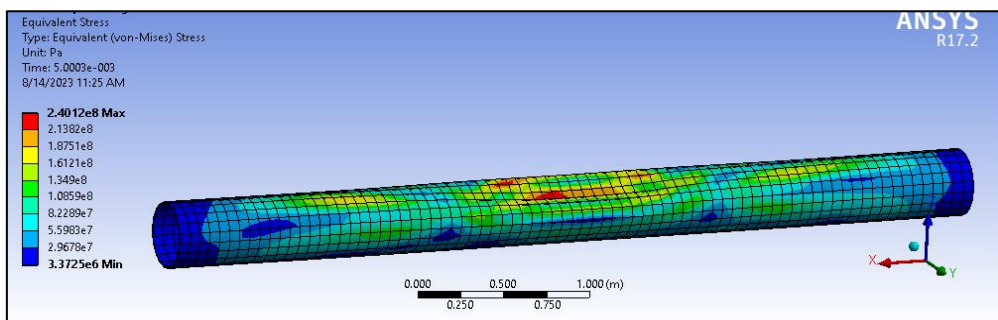**Figure 7.** Deformation value in pipes that use protection

Figure 8. Equivalent Stress Value for pipes that use protection

Table 5. Deformation and Equivalent Stress values based on ANSYS simulation

No	Model	Pipe Thickness (m)	Deformation (m)	Equivalent Stress *(MPa)*
1	Pipe model without lining	-	0,143	1150
2	Pipe model with lining	0,15	0,076	240

Table 6. Consequences of dropped anchor

No	Result	Anchor drop Velocity (m/s)	Deformation (m)	Deformation/diameter %	Consequence level
1	Analysis	5,492	0,158	39	5
2	Software ANSY	5,492	0,143	35	5

In Table. 6 it is known that the deformation value obtained based on analysis is different from the deformation value obtained from results using ANSYS software, where the level of damage resulting from analytical calculations is 39% while the results obtained using ANSYS are 35%. This is because calculations using the DNV equation only pay attention to the calculation aspect alone, which is different from using software analysis which is more detailed and accurate because this analyst not only pays attention to the calculation aspect but also uses the materials used by the structure being tested which of course can influence the analysis results. However, the results of both have similarities, namely the deformation values obtained are at the same consequence level, namely level 5, the consequence level level 5 is at the highest level where the pipe

experiences fatal damage or breaks which causes the pipe to have to be replaced. For more details regarding the safe limits or maximum deformation values for unprotected pipes, see Figure 9.
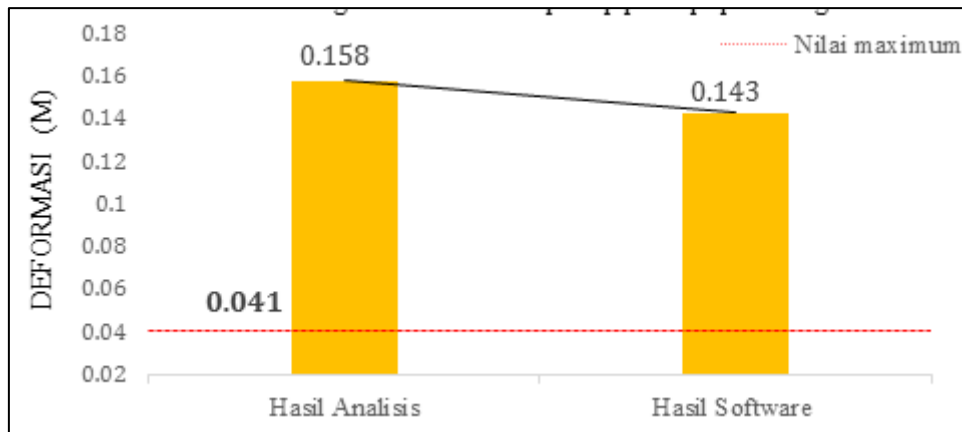

Figure 9. Deformation value based on software analysis and results
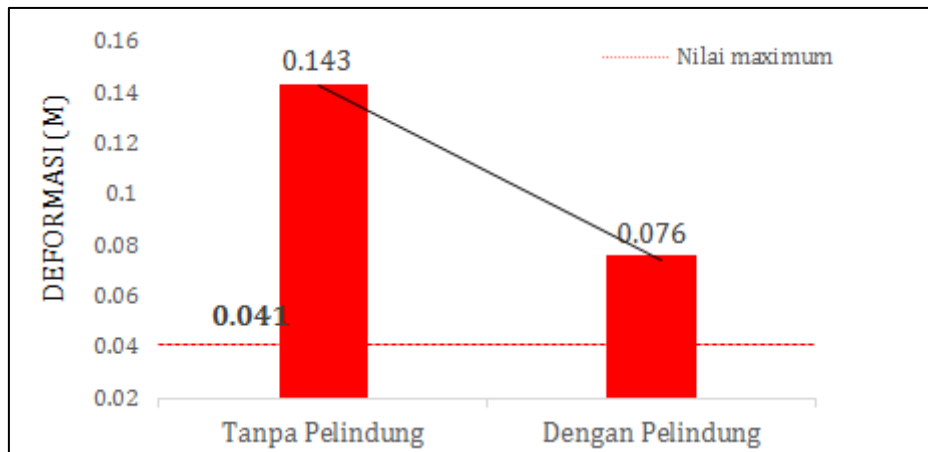

Figure 10. Deformation value based on ANSYS software

In Figure 10 it is known that the deformation value obtained based on the software is 0.143 m for pipes without protection and for pipes using protection it is 0.076 m. This means that the use of pipe protection with a thickness of 0.15 m is quite effective in reducing the impact of damage to the pipe, however. has not been able to protect the pipe from damage completely because the pipe damage is still above the specified maximum deformation value, namely 0.041 m.

3.6. Variation of Speed Values

To find out at what speed the anchor falls and hits the pipe, causing the pipe to experience maximum deformation or total damage, using 2 methods, namely analysis and simulation results. For analysis, it was found that a falling anchor with a speed of 11.14 m/s could cause total damage to the pipe that was obtained, calculated using the following equation.

$$\delta = \left(\frac{E.9^{1/2}.t^{1/2}}{16.(2\pi)^{\frac{1}{2}}.mp.D^{3/2}} \right)^{2/3}.D$$

$$\delta = \left(\frac{540541,77 \; x \; 3 \; x \; 0,2}{16 \; x \; 2,505 \; x \; 31200 \; x \; 0,259} \right)^{2/3} x \; 0,4064$$

$$\delta = 0,406 \; m$$

Then the second method is using ANSYS. After carrying out several experiments or simulations using ANSYS, it was found that at a speed of 10.4 m/s when the anchor hit a pipe with a diameter of 0.4064 m, the pipe suffered total damage. The deformation value obtained using a

speed of 10.4 m/s can be seen in Table 7 below.

Table 9. The level of consequences that occur on pipes using protection

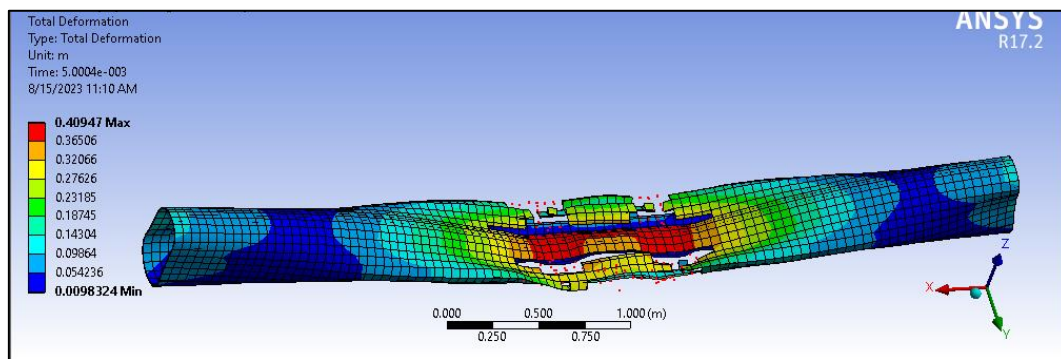| No	Model	Thickness (m)	Deformation (m)	Deformation / Diameter (%)
1	Model without lining	-	0,40	100
2	Model with lining	0,15	0,26	64

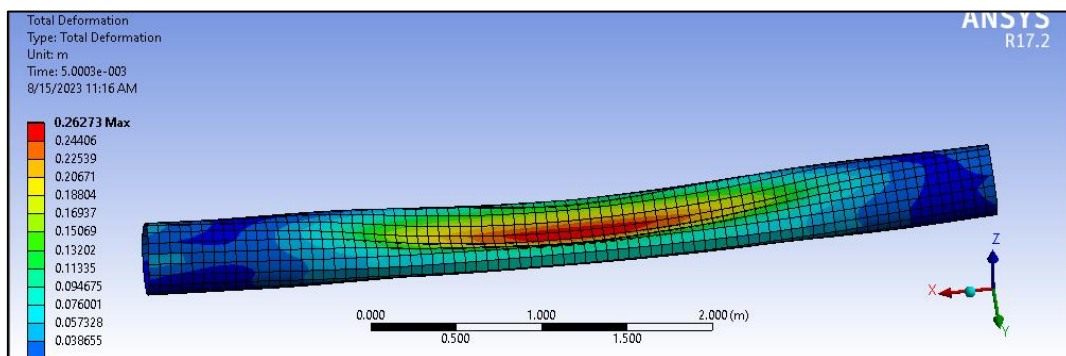**Figure 11.** Unshielded Deformation Value

Figure 12. Assess Deformation using protectors

4. Conclusions

Based on the results of the analysis of the effect of using concrete mattresses on underwater pipes, it was concluded that when the unprotected pipe was hit by a falling anchor at a speed of 5,491 m/s, the pipe experienced significant damage, when viewed from the resulting deformation value it was above the maximum deformation value or around 10 % of the pipe diameter value, and if seen from the equivalent stress value obtained by the pipe without a protector, it is also above the maximum value that has been determined. For pipe models that use a protector with a thickness of 0.15 m, it is proven to reduce the damage caused, however Pipe protectors with a thickness of 0.15 m are not able to protect pipes effectively because the damage that occurs is still above the maximum deformation value that has been determined. However, if you look at the equivalent stress value, the pipe that uses the protector is below the maximum value of equivalent stress that has been determined.

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