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Local Stress Analysis in the Chain Link of Mooring Line That Had Diameter Degradation

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ABSTRACT
Mooring systems are used to moored ships at a particular area. One of its type is SPM by using a buoy. The system generally uses chains used to tie buoys to the seabed. However, chains that are used continuously can experience degradation in the diameter of the chain connection. The degradation experienced by the connections between the chains will certainly affect the local (von Mises stress). According to ABS rules, the amount of local stress or von Mises stress that occurs on an object must not exceed 90% of the yield strength of the material. Therefore, it is necessary to do a local stress analysis to determine the extent of degradation of the diameter of the chain connection so that the local stress value does not exceed that allowed. The largest mooring tension value that occurs in the mooring system is 1838,252 kN. The results show that if the chain connection is subject to a tension of 1838,252 kN, the diameter degradation that occurs in the chain connection must not exceed 15% of the initial diameter so that the local or von Mises stress does not exceed 369 MPa (90% of the yield strength of the material 410 MPa).

Keywords: ANSYS, *mooring, chain diameter degradation, von Mises stress*

1. INTRODUCTION

Mooring systems are generally used to anchor ships at a particular place, such as at a port or offshore so that the building cannot move from a predetermined place. Several mooring systems can be used to tether a floating building, one of which is the Single Point Mooring method [1]. SPM is a floating structure that functions as a mooring of floating buildings on the seabed, including ships [2]. In general, mooring lines used for SPM systems in offshore areas are chains because they have a high breaking strength. In the field conditions, the chain will occur degradation or reduction in diameter. Degradation is generally caused by corrosion, age factors and usage factors [3]. The corrosion factor is caused by the mooring chain that is used in general will be exposed directly to seawater which can accelerate corrosion. Several attempts were made to minimize the diameter reduction that occurs in the chain, such as providing cathodic protection to reduce the rate of corrosion in the mooring chain, but it was not effective enough in reducing the corrosion rate in the mooring chain [4-6].

Figure 1. Chain Diameter Degradation [7]

Several researchers have been carried out to determine the value of the tension in the connection between chains, such as those conducted by Bastid et al (2013) and Oikonomidis et al (2019). Both researchers have calculated the value of the stresses and stress concentrations that occur in the connection between mooring chains [8,9], but this study did not pay attention to the effect of reducing the diameter of the connection between chains. Reducing the diameter of the connection between mooring chains will greatly influence the strength of the chain. If this is ignored, then there will be obstacles in the mooring system in the form of a broken chain at the SPM, so that it can endanger the ship and crew. Thus, it is necessary to carry out an activity in the form of inspection of the diameter of the chain connection so that the local stress (von Mises Stress) that occurs does not exceed the allowable stress. Following ABS rules, the amount of local stress or von Mises stress that occurs on an object must not exceed 90% of the yield strength of the material [10]. So it is necessary to analyze the local stress on the connection between the chains that experienced a diameter degradation to determine the degradation limit that occurs so that the value of the local stress does not exceed the permitted stress.

2. MATERIALS AND METHODS

This research stage was carried out starting from the study of literature from various journals and previous research. Then the next stages of research are as follows:

a. Data collection
   Data collection is done by the author by collecting data in the form of ship data, buoy data, mooring data, and environmental data.
b. Modeling on ORCAFLEX
   Perform SBM models and mooring configurations on ORCAFLEX. After that, inputting the RAO results for each structure and its environmental burden.
c. Tension analysis on mooring chain
   This process aims to carry out dynamic analysis on the mooring chain to get the greatest tension that occurs in all conditions using ORCAFLEX software.
d. Modeling on AutoCAD
   Modelling the chain connection in each diameter degradation conditions in AutoCAD.
e. Analysis of local stresses on ANSYS
   This process aims to perform local stress analysis on the connection between mooring chains in each diameter degradation conditions to get the magnitude of von Mises stress that occurs from all conditions using ANSYS software.

3. RESULTS AND DISCUSSION

3.1 Mooring System Analysis

The mooring system modelling is done using ORCAFLEX software. The reason for using the ORCAFLEX software is because the output of this software is a tension value on each line, where the largest tension obtained will be inputted into ANSYS. But before that, the author doing modelling on the buoy in MOSES to know the RAO from it. The data used in this analysis are.

Table 1. Mooring System Data

Description	Unit	Data
***Line* 1 and *Line* 4**		
Type	-	Studlink - Chain
Grade	-	U3
Diameter	mm	58
Minimum Breaking Load (MBL)	kN	2600
Line 2 and Line 3		
Type	-	Studlink - Chain
Grade	-	U3
Diameter	mm	58
Minimum Breaking Load (MBL)	kN	2600
Length	m	55
Line 2 and line 3		
Type	-	Studless - Chain
Grade	-	Grade R4
Diameter	mm	82.5
Minimum Breaking Load (MBL)	kN	6974.773
Hawser		
Type	-	Rope
Grade	-	Polypropilene
Diameter	inch	9
Minimum Breaking Load (MBL)	kN	(unknown)

(Source : PT. Pertamina-TBBM Semarang Group)

Table 2. Buoy Data

Description	Unit	Data
Displacement (Δ)	ton	132.89
Diameter *buoy*	m	8
Diameter *skirt*	m	11.24
Buoy Height	m	3.7
Skirt Height	m	0.8
Draft	m	1.8
VCG	m	2.22

(Source : PT. Pertamina-TBBM Semarang Group)

Table 3. Anchor Location

Objects	UTM WGS.84		Geographic	
	Easting	Northing	Longitude (T)	Latitude (S)
SPM	436 996.76	9 238 580.08	110°25' 47.02"	6°53' 17.43"
PLEM	437 001.6	9 238 559.7	110°25' 47.17"	6°53' 17.94"
Anchor no.1	436 770.96	9 238 727.84	110°25' 39.56"	6°53' 12.78"
Anchor no.2	437 160.99	9 238 834.45	110°25' 52.31"	6°53' 09.19"
Anchor no.3	437 134.74	9 238 441.56	110°25' 51.63"	6°53' 21.93"
Anchor no.4	436 853.34	9 238 429.82	110°25' 42.34"	6°53' 22.11"

(Source : PT. Pertamina-TBBM Semarang Group)

From Table 2, we get the buoy modelling on MOSES. The buoy model has been modelled in Figure 2 below.

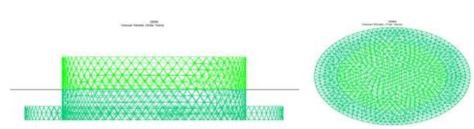


Figure 2. Buoy Model

After that, the response analysis is performed at MOSES to determine the RAO response value of the buoy in free floating conditions. RAO explains the motion characteristics of a structure due to the observed environmental load. The motion characteristics of this ship are presented in the form of an RAO graph, where the abscissa shows the frequency parameter and the ordinate shows the ratio between the amplitude of movement in a particular mode [11]. RAO buoy graph on translational movements (surge, sway, heave) is shown in Figure 3. to Figure 5 below.

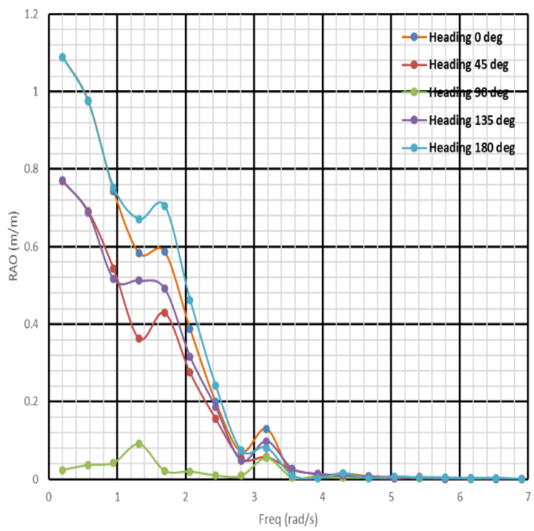


Figure 3. Buoy Surge RAO

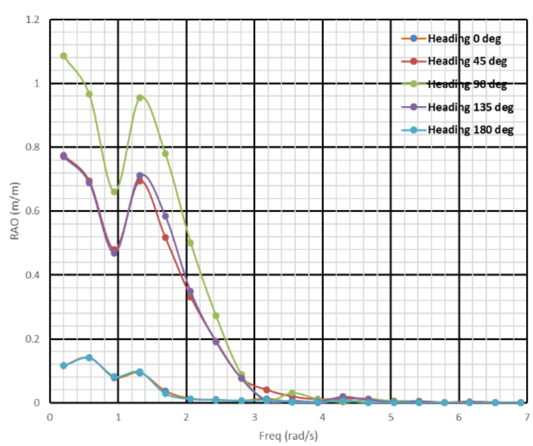


Figure 4. Buoy Sway RAO

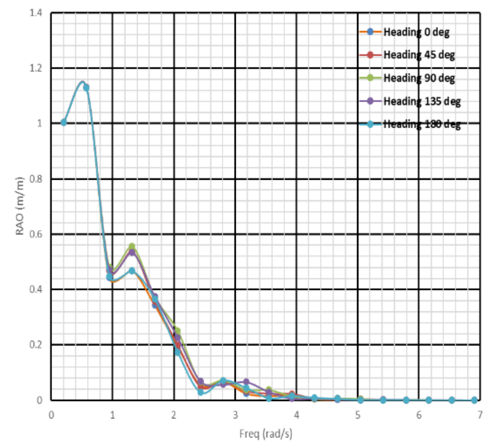


Figure 5. Buoy Heave RAO

From Figure 3 to Figure 5, we get the response value for the translation movement mode shown in Table 4. below.

Table 4. RAO Buoy Value of Translational Motion

DOF	**RAO (m/m)**					
	0 deg	**45 deg**	**90 deg**	**135 deg**	**180 deg**	**MAX**
Surge	1.089	0.769	0.088	0.771	1.089	1.089
Sway	0.141	0.775	1.087	0.771	0.141	1.087
Heave	1.13	1.129	1.13	1.129	1.129	1.13

From Table 4 above, we get the RAO buoy value in the translational motion which occurs in the heave movement with a value of 1.13 m / m on the heading 90 deg. After that, the RAO buoy graph on the rotational motion (roll, pitch, yaw) is shown in Figure 6 to Figure 8 below.

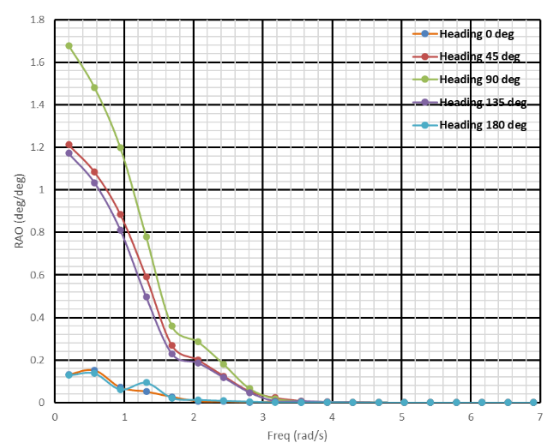


Figure 6. Buoy Roll RAO

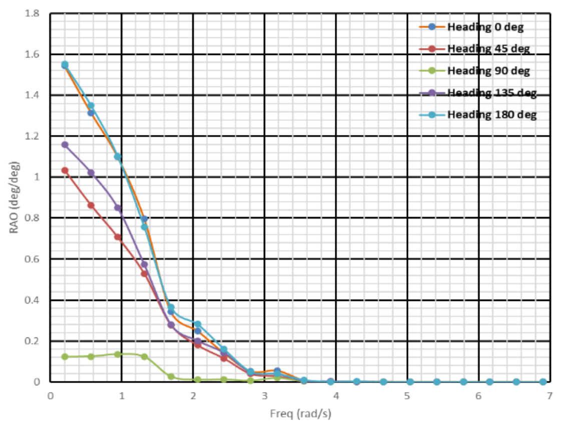


Figure 7. Buoy Pitch RAO

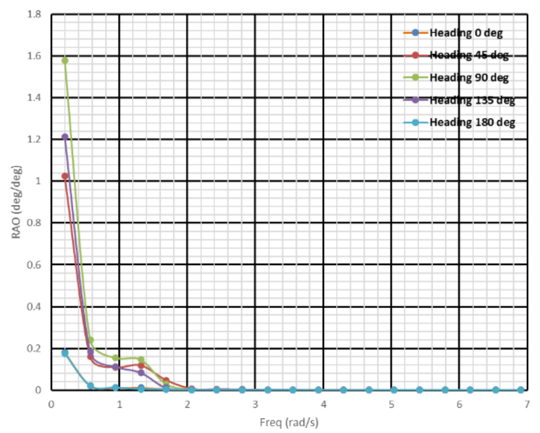


Figure 8. Buoy Yaw RAO

From Figure 6 to Figure 8 above, we get the response value for the rotational motion mode shown in Table 5 below.

Table 5. RAO Buoy Rotation Motion

DOF	RAO (deg/m)					
	0 deg	45 deg	90 deg	135 deg	180 deg	MAX
Roll	0.148	1.208	1.674	1.169	0.135	1.674
Pitch	1.539	1.030	0.131	1.156	1.548	1.548
Yaw	0.146	0.831	1.28	0.984	0.142	1.28

From Table 5 above, we get the RAO buoy value on the rotational motion occurring on the roll movement with a value of 1,674 deg / m on the heading 90 deg. After that, mooring layout modelling is carried out in accordance with Table 1. and Table 3. and entering the response values that have been obtained. After that, a dynamic simulation is performed on ORCAFLEX with a simulation duration of 1800 s. After that, the mooring system layout which has the largest tension value is shown in Figure 9 below.

Figure 9. Mooring System Layout with Highest Tension Result

The greatest tension occurs in the condition of the direction of environmental loading that is non-collinear and inline to L2 (Figure 9). The amount of tension that occurs in mooring lines is shown in Table 6. below.

Table 6. Highest Tension Result

Line	Tension (kN)	MBL	SF
L1	553.492	2600	4.70
L2	1838.252	2600	1.41
L3	467.291	2600	5.56
L4	288.231	2600	9.02

From Table 6 above, it can be concluded that the greatest tension occurs at L2 with a value of 1838,252 kN. This tension value will later be used as a load input in local stress analysis using ANSYS.

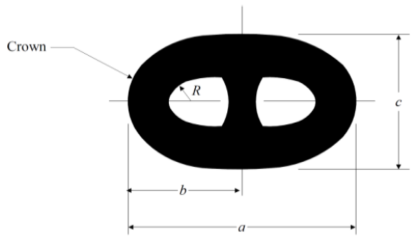
3.2 Chain Diameter Degradation Modelling

Modelling of connections between chains in each diameter degradation condition is carried out using AutoCAD software. This modelling is done to create an object analysis model which will be used as input to ANSYS. But before that, it is necessary to determine the number of diameter degradation conditions to be analyzed. The diameter degradation conditions used are shown in Table 3.7 below.

Table 7. Chain Diameter Degradation Conditions

Condition (s)	%Degradation	Dnew (mm)	Dcorr (mm)
1	0%	58	58
2	5%	58	55.1
3	10%	58	52.2
4	15%	58	49.3
5	20%	58	46.4
6	25%	58	43.5

From Table 7. it can be seen if there are six diameter degradation conditions with a degradation percentage from 0% to 25%. The result of a large diameter that has been graded (Dcorr) refers to the initial diameter of the chain (Dnew) minus the percentage of chain degradation. Modelling of the chain connection is done by considering the dimensions of the dimensions under the rules of BKI Rules of Materials 2019 shown in Figure 10, and the area subject to diameter reduction in the chain is shown in Figure 3.10 below.



Designation 1)	Description	Nominal Dimensional of the Link	Minus Tolerance	Plus Tolerance
a	Link Length	6d	0.15d	0.15d
b	Link Half Length	a*/2	0.1d	0.1d
c	Link Width	3.6d	0.09d	0.09d
e	Stud Angular Misalignment	0 degrees	4 degrees	4 degrees
R	Inner Radius	0.65d	0	-----

1) Dimensional designation is shown in above figure
d = nominal diameter of chain, a* = actual link length

Figure 10. Studlink Chain Dimension Criteria [12]

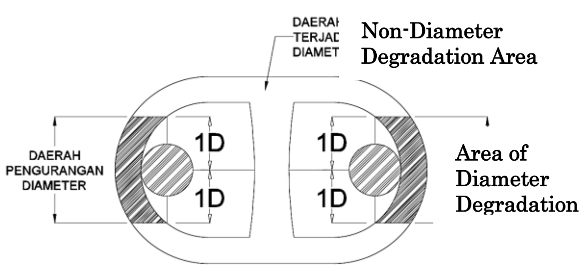


Figure 11. Area of Chain Diameter Degradation

Based on Figure 10 and Figure 11 above, the results of chain link modelling in AutoCAD are shown in Figure 12 and Figure 13 below.

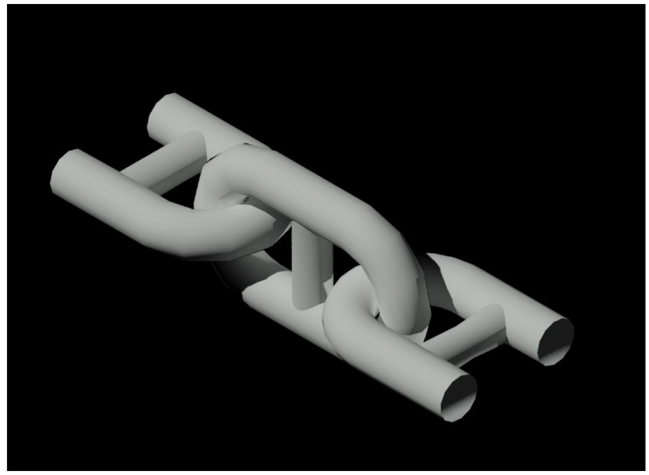


Figure 11**.** Chain Model Without Degradation

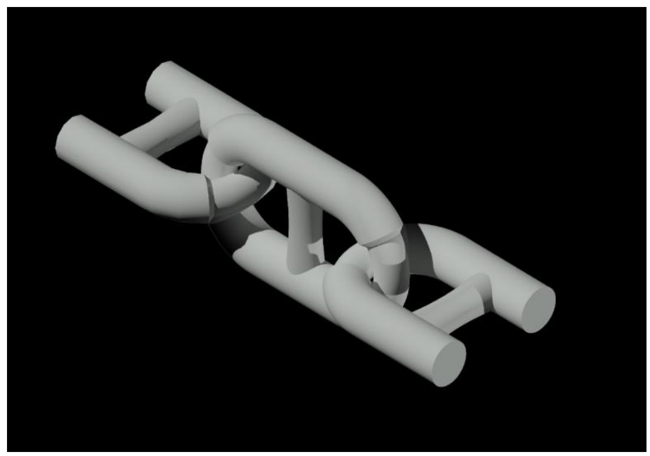


Figure 12. Chain Model With Degradation

3.3 Von Mises Stress Analysis

Von Mises stress is the stress used to predict the yield rate of an object or material that is affected by the load [13]. Tensions that work on an object can cause the object to melt. In ANSYS software, local stress calculations are performed using the FEM (Finite Element Method) method. Therefore, the writer needs to mesh the object. Meshing is the activity of dividing objects into smaller parts. Small parts of an object can be called elements [14]. Meshing itself can be illustrated according to Figure 3.13 below.

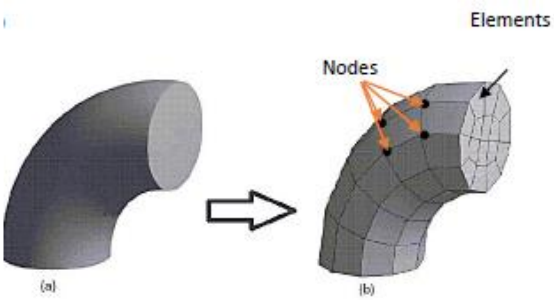


Figure 14. *Meshing* in an Object [14]

From the explanation above, we get the type of meshing in all diameter degradation conditions with the type of element namely tetrahedron shown in Figure 15 below.

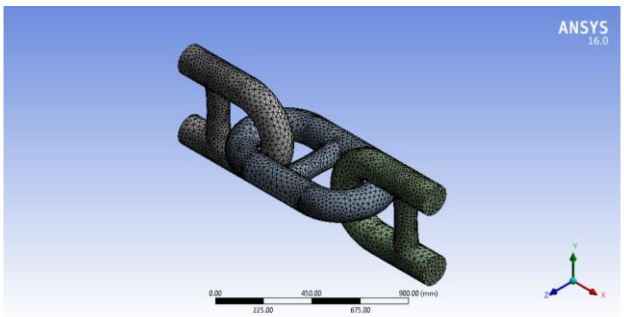


Figure 15. Mesh Element

After meshing, the boundary conditions are then determined. Boundary conditions on ANSYS consist of the type of load and the type of support used under the real conditions on the object analyzed. Boundary conditions used in this analysis are fixed support and load is in the form of force. The reason fixed support is used is that to hold an object in the form of vertices, edges, surfaces, or solid bodies not to move translatively in the direction of the x, y, z-axis and rotate to the x, y, z-axis when exposed to a load of force [15]. The magnitude of the force used in this analysis is 1838,252 kN. Boundary conditions used in this analysis are shown in Figure 16 below.

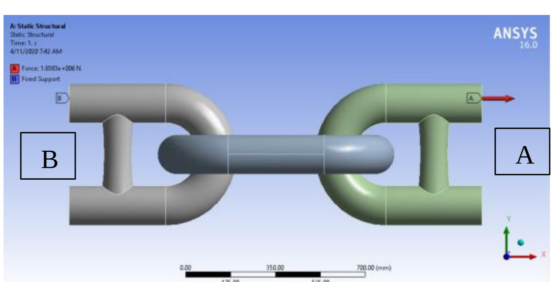


Figure 16. Boundary Condition

From Figure 16, it can be seen if area A is the area affected by force, and area B is the fixed support area. From Figure 3.15 above, the local stress or von Mises stress will be obtained later. After getting the local stress value, it is necessary to do mesh sensitivity to check whether the local stress results obtained are constant in every change in the number of mesh elements. If it is constant, then the local stress value obtained is correct. For condition 1, the obtained mesh sensitivity is shown in Table 8 below.

Table 8. Mesh Sensitivity in First Conditon

No.	Element (s)	Von Mises (MPa)
1	71149	299.11
2	74186	304.54
3	88378	309.41
4	93478	309.52

The results of local stress in the first condition are shown in Figure 17 below.

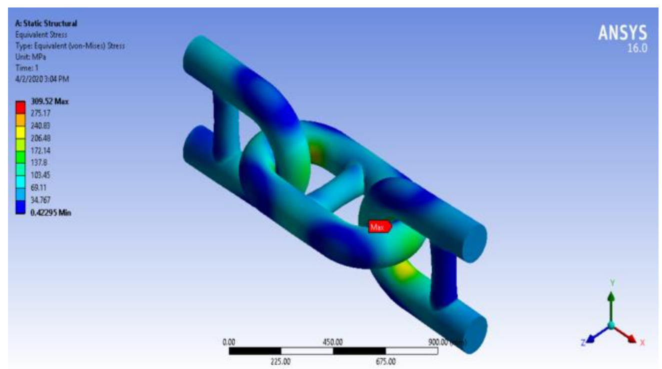


Figure 17 Von Mises Stress in The First Condition

From Table 8 and Figure 17 above, we obtain if the local or Von Mises stress value in this first condition is 309.52 MPa. So, it can be concluded if the value of local stress in this first condition still meets the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa). For the second condition, the mesh sensitivity obtained is shown in Table 9 below.

Table 9 Mesh Sensitivity in Second Condition

No.	Element (s)	Von Mises (MPa)
1	46124	313.16
2	62676	323.21
3	95019	324.98
4	98729	325.1

The results of local stresses in the second condition are shown in Figure 18 below.

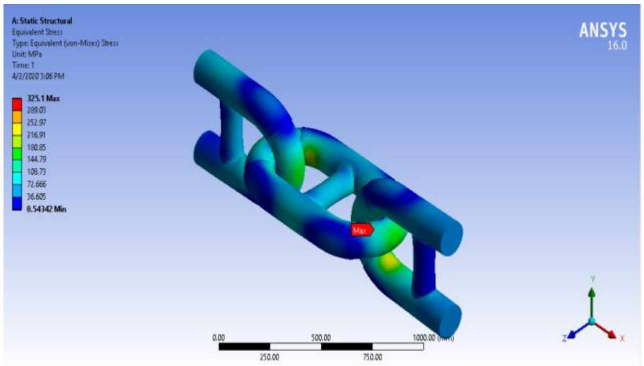


Figure 18 Von Mises Stress in The Second Condition

From Table 9 and Figure 18 above, we obtain if the local or Von Mises stress value in this second condition is 325.1 MPa. So, it can be concluded if the local stress value in the second condition still meets the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa). For the third condition, the obtained mesh sensitivity is shown in Table 3.10 below.

Table 10. Mesh Sensitivity in Third Condition

No.	Element (s)	Von Mises (MPa)
1	49595	305.79
2	50119	350.79
3	66790	346.54
4	93522	346.76

The results of local stresses in this third condition are shown in Figure 19 below.

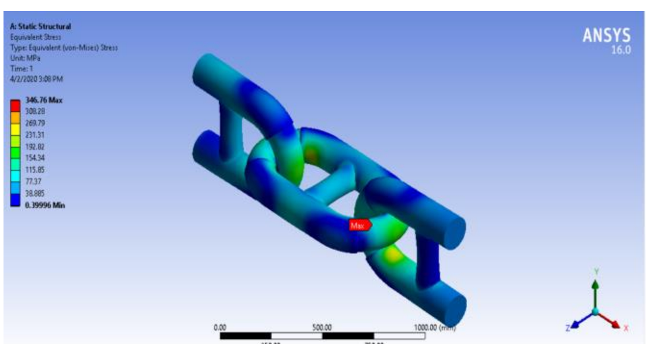


Figure 19. Von Mises Stress in The Third Condition

From Table 10 and Figure 19 above, it is obtained if the local or Von Mises stress value in this third condition is 346.76 MPa. So, it can be concluded if the value of local stress in this third condition still meets the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa). For the fourth condition, the obtained mesh sensitivity is shown in Table 3.11 below.

Table 11. Mesh Sensitivity in Fourth Condition

No.	Element (s)	Von Mises (MPa)
1	57001	328.8
2	63289	371.19
3	71655	361.09
4	101094	361.97

The results of local stresses in this fourth condition are shown in Figure 3.19 below.

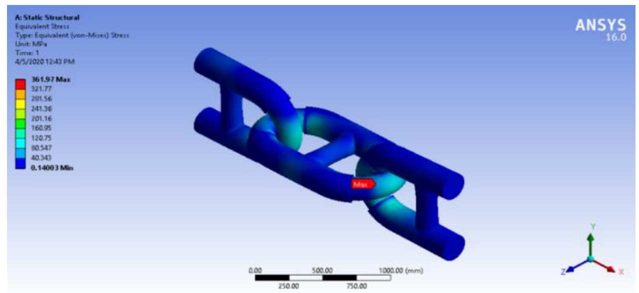


Figure 20. Von Mises Stress in The Fourth Condition

From Table 11 and Figure 20 above, it is obtained if the local or von Mises stress value in the fourth condition is 361.97 MPa. So, it can be concluded if the local stress value in the fourth condition still meets the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa). For the fifth condition, the mesh sensitivity obtained is shown in Table 12 below.

Table 12. Mesh Sensitivity in Fifth Condition

No.	Element (s)	Von Mises (MPa)
1	31880	421.14
2	81572	400.75
3	95653	401.1
4	99183	401.61

The results of local stresses in this fifth condition are shown in Figure 21 below.

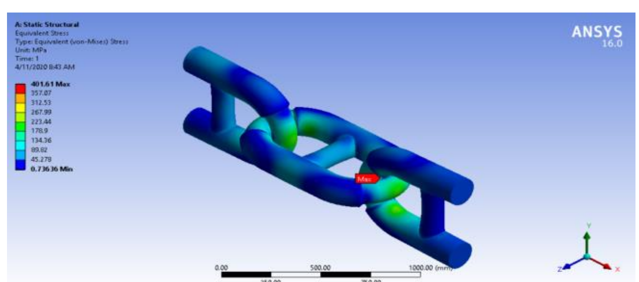


Figure 21. Von Mises Stress in The Fifth Condition

From Table 12 and Figure 21 above, we get it if the local or von Mises stress value in the fifth condition is 401.61

MPa. So, it can be concluded if the local stress value in the fifth condition does not meet the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa). For the sixth condition, the mesh sensitivity obtained is shown in Table 13 below.

Table 13. Mesh Sensitivity in Sixth Condition

No.	Element (s)	Von Mises (MPa)
1	34267	505.13
2	69118	435.75
3	92612	442.13
4	97499	442.94

The results of local stresses in this sixth condition are shown in Figure 22 below.

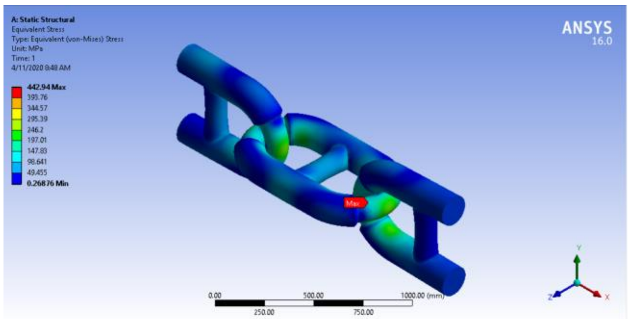


Figure 22. Von Mises Stress in The Sixth Condition

From Table 13 and Figure 22 above, we get it if the local or von Mises stress value in the sixth condition is 442.94 MPa. So, it can be concluded if the local stress value in the sixth condition does not meet the ABS criteria, where the allowable local stress value is 369 MPa (90% of material yield strength is 410 MPa).

4. CONCLUSION

From the above research, it can be concluded if:

1. The author analyzes the response to the buoy structure, and it is found that the greatest response to the translational motion occurs in the heave movement with a value of 1.13 m / m at heading 90 deg, while the largest response to the rotational motion occurs at the roll motion with a value of 1,674 deg / m at heading 90 deg.
2. The author conducts a local stress analysis on the chain connection that experiences a diameter degradation using finite element method. There are 6 diameter degradation conditions in the connection between chains analyzed to get the value of local stress (von Mises Stress) at each diameter degradation condition. The force applied to the chain is 1838,252 kN and the allowable local stress value (according to ABS criteria) is 369 MPa (90% of material yield strength that is 410 MPa). The amount of local stress that occurs in the chain connection in every condition of diameter degradation is.
   a. The local stress value at condition 1 (-0%) is 309.52 MPa
   b. The local stress value at condition 2 (-5%) is 325.1 MPa
   c. The local stress value at condition 3 (-10%) is 346.76 MPa
   d. The local stress value at condition 4 (-15%) is 361.97 MPa
   e. The local stress value at condition 5 (-20%) is 401.61 MPa
   f. The local stress value at condition 6 (-25%) is 442.94 MPa

From the description above, it can be concluded if the diameter degradation that occurs in the connection between chains should not exceed 15% so that the local stress value (von Mises Stress) does not exceed the allowable value of 369 MPa.

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