EPI International Journal of Engineering
Volume 5, Number 1, February 2022, pp. 1-9
DOI: 10.25042/epi-ije.022022.01

*p*ISSN 2615-5109
*e*ISSN 2621-0541

Strength Analysis due to the Elongation's Ladder of Cutter Suction Dredger Ship

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Abstract

The more frequent mining activities are carried out, the deeper the tin on the seabed, therefore many ship owners want to increase the length of the ladder on production suction vessels. The owner of the KIP Timah 8 suction boat will increase the length of the ladder to 70 meters, which previously was only 58 meters. The paper research are the response of the ladder structure before and after being extended, the limit strength of the ladder structure in the pulley area, then the ultimate strength of the longitudinal ladder structure due to the vertical bending moment. Lenght of the ladder construction subsequently increases commencing 58 m, 62 m, 66 m, to 70 m with each increase in length varying the slope angle of the ladder starting from 0^o, 30^o, 45^o, to 60^o. This paper uses a numerical method with the help of ansys software. The structure being reviewed is only in the ship ladder area. The response of the ladder structure before and after being extended, the maximum stress value occurs in the strut construction which is 49 meters from the ladder shaft, which is 56.88 N/mm2 and the maximum shift is 14.28 mm when the ladder length is 70 meters and still meets the allowable stress. Investigation of the limit strength using the Nonlinear Finite Element Analysis (NLFEA) method. Based on the results the analysis of the strength longitudinal ladder structure in the hogging and sagging conditions 42 meters from the ladder shaft, the maximum deflection in the column is 131.73 mm from the initial position before being loaded. While at an angle of 60 degrees it will collapse when deflection 66.17 mm. The results of the analysis showed that the load acting on the ladder the pipe load, cutter load and cutter torque the resulting stress still meets the stress that the longer ladder is directly proportional to the resulting stress and deflection value and the greater the slope of the ladder, the smaller stress and deflection.

Keyword: *Bending moment; NLFEA*; *ladder; ultimate strength*

1. Introduction

Bangka, Belitung and Batam island the highest tin producers in Indonesia both on land and at sea. Currently, the economic driver for this region is still dominated by the tin processing sector. The management of tin mining must be as good as possible in order to benefit many parties. Mining at sea requires facilities such as ships. The ship used to mine tin is called the Kapal Isap Produksi (KIP), which is a digging or soil removal tool used to dig the subsoil, mechanical equipment and material processing rests on a pontoon. The sub-soil containing tin sand is cut using a cutter/cutter. As a floating device, the hallmark of a Kapal Isap Produksi (KIP) is that it consists of 4 capsules (Pontoon), the right and left side capsules are shorter and two capsules in the middle are longer. There is also a ladder, which is a long steel frame that functions as a pole and a place for placing suction pipes, mud pumps, pressure pipes and cutters located at the end of the ladder as a cutter that is installed in the middle of the ship which is used to dig for tin on the seabed.

Maximum inclination of the ladder when operating is 60 degrees. The tin on the seabed is getting deeper because mining is often carried out so that many ship owners want to increase the length of their ship's ladder in the hope that they can still reach the seabed to mine tin. Modification of the ship's ladder is done so that it can be used for mining at sea. The Ladder KIP Timah 8 will be extended to be able to mine deeper. Several ladders experienced structural failure on other ships with relatively similar ladder lengths to the length of KIP Timah 8 ladder, possibly due to corrosion, ladder age and ladder strength (structure). Efforts to lengthen the ladder must be carried out with reliable calculations so that there will be no failure since cost of repairing a broken ladder is very expensive 6 billion. Therefore an

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analysis of the ladder structure is necessarily to be conducted to minimize the level of damage (broken) on the ladder ship.

This paper presents research are the response of the ladder structure before and after being extended, the ultimate strength of the ladder structure in the pulley area, then the ultimate strength of the longitudinal ladder structure due to the vertical bending moment. In order for the simulation of the analysis of the ladder strength the production suction ship in accordance with the reality, use the existing ladder data. The type of data in this paper is secondary data. Secondary data is data obtained from sources related to the object of research, including pictures of stairs construction and materials used. The initial stage in the analysis is the collection of preliminary data in the form of the main dimension of the ship, the drawing of the ladder. Then the calculation of pipe load, cutter load and cutter torque is carried out. After that, ladder structure modeling is carried out for each length increase ranging from 58 meters, 62 meters, 66 meters and 70 meters. Each increase in length varies the angle of the ladder ranging from 0 degrees, 30 degrees, 45 degrees and 60 degrees.

1.1. Mining Technical at KIP Timah 8

Kapal Isap Produksi (KIP) Tin 8 is owned by PT. Timah (Persero) has dimensions of a total length of 85.5 meters, a total width of 22 meters, and a total height of 10.5 meters with a cutter section dredger type and started operating in 2010. The operation of KIP is determined from the specifications of the excavation equipment, namely the length of the ladder and the maximum angle of the ladder. with a water surface that affects the maximum depth that can be produced. Pontoons are a very important part of the operation of KIP. A pontoon is a floating object whose role is to hold the ship afloat. KIP's pontoon is made of hollow steel in the form of a capsule and the pontoon is divided into four main parts, namely two inner pontoons and two outer pontoons. The pontoon is divided into several compartments as shown in Fig. 1.

Superstructure is the part that functions as a means of supporting the other parts so that the ship's construction is stronger and more durable. In KIP there are two main decks, namely the lower deck and the upper deck. All equipment on the upper deck is held by the hull so that the ship remains stable as for the propulsion engine, hydraulic engine and ladder as shown in Fig. 2.

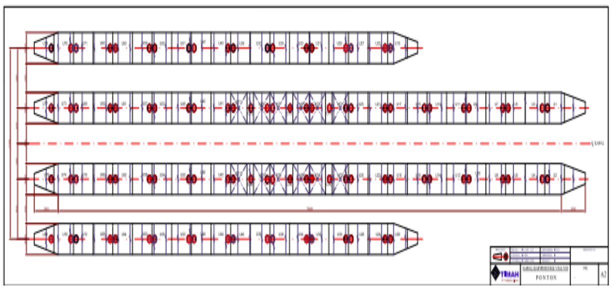

Figure 1. Schematic the pontoon [1]

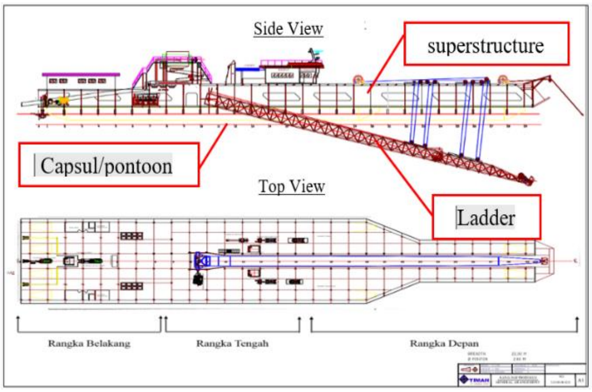

Figure 2. Top view and side view of KIP Timah 8 [1]

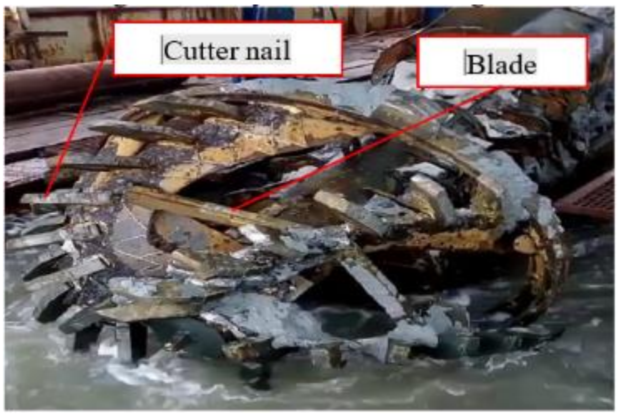

Figure 3. Cutter head [1]

Figure 2 is the construction of a Kapal Isap Produksi (KIP) Timah 8 which consists of a superstructure with a girder profile connected to the pontoon and also equipped with a cutter head on the ladder as a tool for cutting the soil layer as shown in Fig. 3.

1.2. Pipe Construction

In general, pipe is a term used to designate a hollow tubular body used to transport any impurities that have flow characteristics such as those found in liquids, gases, vapors, liquid solids, and fine powders. Just as there are different manufacturing methods, there are also different ways to categorize pipe sizes. Pipes are identified by three different size categories: nominal pipe size, outside diameter, and inside diameter as in Fig. 4 [2].

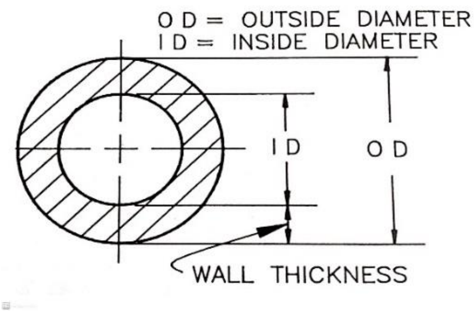

Figure 4. Pipe diameter [2]

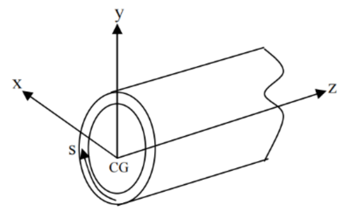

Figure 5. Coordinates of thin walled beams [5]

Laser measurements are used to get the exact shape of the steel pipe; Based on the digital inverse modeling technology, the actual constitutive equation of the steel pipe material is introduced to perform precise simulations on the buckling behavior of steel pipes under internal stress and bending conditions, and establish a technological numerical simulation for the buckling strain capacity of steel pipes [3].

The formulation in the beam finite element is based on the theory of thin-walled beams. Here, the fundamental theory of thin-walled beam elements includes torsional effects as a general case [4]. The x and y axes are defined on the beam cross section and the z axis is parallel to the beam axis. The origin of the coordinate system is located at the center of gravity of the cross section. The s-coordinate is defined along the center thickness line. Assuming that the cross section remains undistorted during deformation, the displacements U, V and W in Equations (1, 2, and 3) at x, y, and z at coordinates (x, y, z) can be expressed as in Fig. 5 [5].

$$U(x,y,z) = u_s(z) - (y-y_s)\theta(z) \tag{1}$$

$$V(x,y,z) = v_s(z) + (x-x_s)\theta(z) \tag{2}$$

$$W(x,y,z) = w(z) + xu'_s(z) - yv'_s(z) + \omega_{ns}(x,y)\theta'(z) \tag{3}$$

Where u_s and v_s are the displacements at the center of shear in the x and y directions and w are the displacements at the center of gravity in the z direction. is the angle of rotation about the center of shear. x_s and y_s are the x and y coordinates of the center of shear. ns is the bending function in the central shear. The prime number (') indicates the differentiation to the z-coordinate [5].

1.3. Frame Structure

Frame structure is a structure whose elements consist of tensile bars, columns, beams, and bars that are subjected to bending and axial loads. Most common building constructions that fall into this category are high rise buildings which usually consist of beams and columns that are rigidly joined or with simple end joints with diagonal bracing for stability. Although multi-storey buildings are three-dimensional in shape, when designed with rigid joints, they usually have much greater rigidity in one direction than in the other [6]. Several cross-sectional shapes such as square, round, angled, rectangular and various others are produced in a wide range of sizes and are used as well as flat plates and solid bars of various thicknesses. The wide wing profile is a profile that is widely used as a plate holder as shown in Fig. 6 [4].

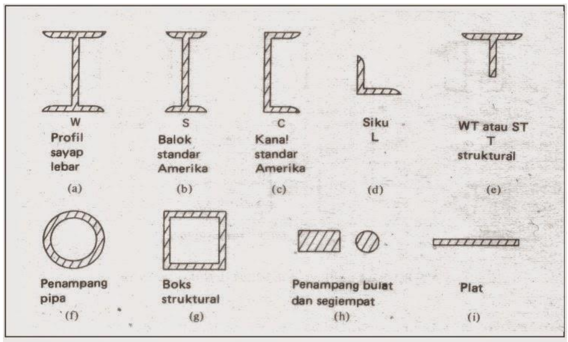

Figure 6. Cross section of the profile [4]

The bracing system serves to help transmit horizontal loads to the foundation, protect the integrity of the structure during the fabrication and installation process, and resist jolts from the installed jacket-pile system. as well as supporting the corrosion anode and well conductors and transmitting the generated wave force to the foundation. Another important characteristic of the tubular frame is the stability of the cross section which is expressed in the diameter/wall thickness ratio (d/t) which also indicates stability against local buckling. The buckling strength at the toe of the deck must be designed so that the deck platform has sufficient strength not only to support but also for the safety of people working on the platform including all facilities [7].

1.4. Loads Acting on the Structure

Dead load is a load that comes from the weight of the ladder structure itself and the weight of various permanent equipment located on the ladder structure and additional equipment whose weight does not change under operating conditions [7]. Live loads are loads that apply to the structure during its operation only and can vary during operating conditions or from operating conditions to other conditions. live load is a gravity load on a structure, which varies in size and location, examples of live loads are humans, furniture, movable equipment. Since the weight, location and density of live loads are unknown, the actual magnitude and position of these loads are very large. difficult to determine [7].

1.5. Stress, Strain and Deflection

Three positive normal stresses x, y and z, and 6 positive shear stresses, xy, yx, τyz, zy, zx, and xz as shown in Fig. 7 are shown to ensure static balance, as Eq. 4 applies [8].

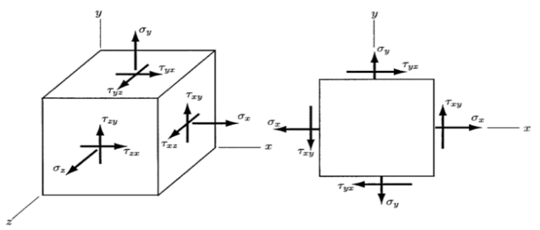

Figure 7. Stress acting on a plane [8]

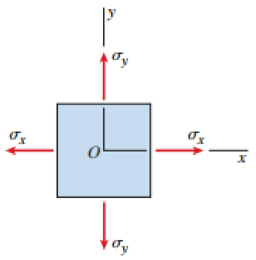

Figure 8. Biaxial stress system [8]

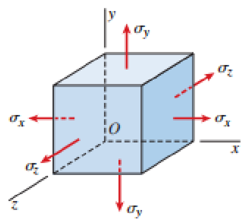

Figure 9. Triaxial stress system [8]

$$\tau_{xy}=\tau_{yx}, \quad \tau_{yz}=\tau_{zy}, \quad \tau_{zx} = \tau_{xz} \tag{4}$$

$$\sigma_x = \frac{E}{(1+v)(1-2v)}[\varepsilon_x (1+v) + v(\varepsilon_y + \varepsilon_z)] \tag{5}$$

$$\sigma_y = \frac{E}{(1+v)(1-2v)}[\varepsilon_y (1+v) + v(\varepsilon_x + \varepsilon_z)] \tag{6}$$

$$\sigma_z = \frac{E}{(1+v)(1-2v)}[\varepsilon_z (1+v) + v(\varepsilon_x + \varepsilon_y)] \tag{7}$$

Strain is a measure of how far the bar is deformed shown in Fig. 8.

In a special case, the biaxial stress as in Fig. 8 occurs when in a structure the axial load acts in two mutually perpendicular axes [8].

The strains produced by the stresses *x*, *y*, and *z* as in Fig. 9 which work independently to obtain the resulting strain can be seen in Eqs. 7, 8, and 9 [8].

$$\varepsilon_x = \frac{\sigma_x}{E} - \frac{v}{E}(\sigma_y + \sigma_z) \tag{8}$$

$$\varepsilon_y = \frac{\sigma_y}{E} - \frac{v}{E}(\sigma_z + \sigma_x) \tag{9}$$

$$\varepsilon_z = \frac{\sigma_z}{E} - \frac{v}{E}(\sigma_x + \sigma_y) \tag{10}$$

Deflection is a change in the shape of the beam in the y direction due to the vertical loading applied to the beam or rod [9]. The allowable stress is the highest stress allowed in a construction or it can be said as the maximum stress that occurs in the construction that is not allowed to be exceeded. In particular, the allowable stress is determined by BKI [10] that the working allowable stress should not exceed the stress in Eq. 11.

$$\text{Stress} = 150/k\ [\text{N/mm}^2] \text{ with } k = \text{steel factor} \tag{11}$$

The stress-strain diagram for a typical structural steel in tension is shown in Fig. 10. Strain on the horizontal axis and stress on the vertical axis.

The relationship between the strength-limit bending moment and curvature is shown in Fig. 11 a positive curvature value indicates a hogging condition and a negative curvature value indicates a sagging condition [12].

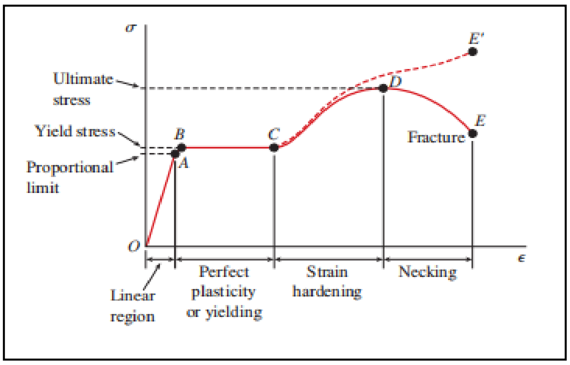

Figure 10. The relationship between stress-strain [11]

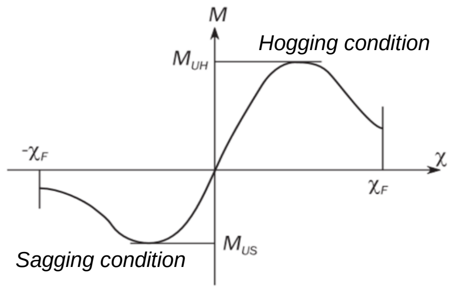

Figure 11. Bending moment strength and curvature [12]

The ultimate strength of the structure depends on various influencing factors, namely geometric/material properties, loading characteristics, related fabrication imperfections, boundary conditions and local dam age related to corrosion, fatigue cracking and deformation [13]. Column members are subjected to yielding and their capacity begins to decrease with increasing deflection. In this sense, the buckling strength of the column member is the maximum load and can be considered as the limiting strength [14]. Ultimate strength for ships that suffered damage to the hull due to aground has been carried out with good results by using Finite Element (FE) [15]. So, with the assumption that the ladder installed on the Kapal Isap Produksi (KIP) Timah 8 can also be calculated with the ultimate strength.

The phenomenon of buckling is usually divided into three categories, namely elastic buckling, elastic-plastic buckling and plastic buckling, the latter two being called inelastic buckling. In-plane stiffness is significantly reduced after the start of buckling. In this case, elastic bending of the seams between the supports may be permitted in the design, sometimes intentionally to save weight of the material. Since significant residual strength of the coating is not expected after buckling occurs in inelastic but inelastic buckling is usually considered as the limiting strength [14].

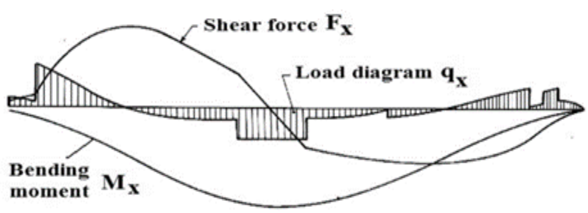

Figure 12. Distribution of loads, shear forces and bending moments on the ship [17]

The bending moments and shear forces in calm water conditions are derived from the buoyancy and weight distribution along the length of the ship as shown in Fig. 12 [16].

2. Research Method

The type of research used is a quantitative simulation to describe the analysis of the strength of the ladder structure for the Kapal Isap Produksi (KIP) Timah 8 after the addition of length. In order for the simulation of the analysis of the strength of the extension of the cutter suction dredger ladder in accordance with reality, the existing ladder data is used. The type of data in this study is secondary data. Secondary data is data obtained from sources related to the object of research, including ladder construction drawings and the materials used. The initial stage in the analysis is the collection of initial data in the form of the main size of the ship, ladder drawings. Then do the calculation of pipe load, cutter load and cutter torque. After that, the structural modeling is modeled for each additional length starting from 58 m, 62 m, 66 m and 70 m. Each increase in length varies the ladder angle starting from 0 degrees, 30 degrees, 45 degrees and 60 degrees.

The ladder model is analyzed using the numerical method is software Ansys, starting from the stages of defining the element type, installing the constraints as shown in Fig. 13.

The ladder model with a vertical bending moment using the multi point constraint (MPC) method, which is given a pedestal at both ends of the ladder model. the end of the ladder shaft is restrained in the x, y and z translational directions and the end of the ladder where the cutter is in the x and y translational bridle. All directions of free rotation are given a moment at one end of the support as shown in Fig. 14.

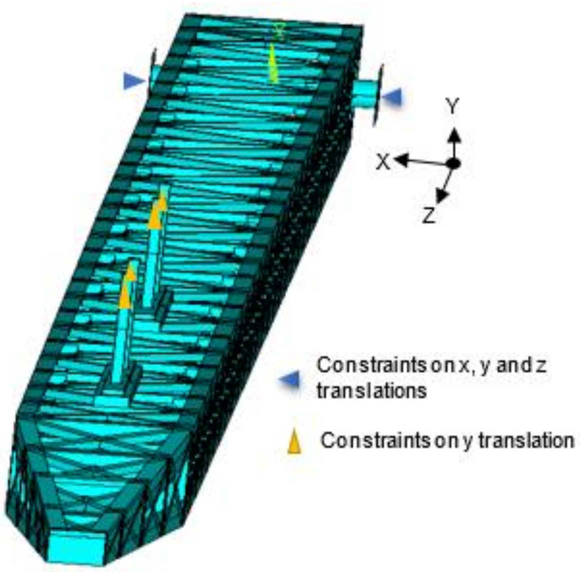

Figure 13. Position of restraint on ladder

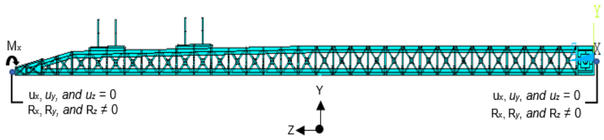

Figure 14. Restraint on the longitudinal strength of the ladder using the Multiple Point Constraint (MPC) method

Table 1. Variation of load increase

Load variation %	Pipe weight x 10^5 N	Cutter weight x 10^5 N	Torque moment x 10^8 Nmm
100	1.42	0.57	0.67
200	2.83	1.14	1.34
300	4.25	1.71	2.01
etc.	etc.	etc.	etc.

After being restrained, the loading and the expected results of the analysis will of course know the stresses and deformations that occur on the ladder after being given a load and also know the highest stress that the ladder can withstand before collapsing.

3. Results and Discussion

3.1. Ladder Structure Loading

Based on the calculation of the load that works on the ladder, the pipe load is 1.42 x 10^5 N, the cutter weight is 5.6 x 10^4 N and the cutter torque is 6.71 x 10^7 Nmm and will vary the load increase every 100% from the initial load until the collapse stress can be summarized in Table 1.

To obtain the value of the vertical bending moment during hogging and sagging conditions for the ladder model, the bending moment will be varied to what extent the ladder construction is able to withstand the moment. In the moment variation experiment, every 100% increased from the initial moment of 5 x 10^7 Nmm until the stress collapses is given in Table 2.

3.2. Ladder Tilt Angle Variation

In this condition, the ladder angle is varied starting from 0^0, 30^o, 45^o, and 60^o with the angle measured between the position of the ladder's slope and the horizontal line of the water surface as shown in Fig. 15.

Table 2. Variation of increase in bending moment.

Bending Moment Variation %	Hogging x10^8 Nmm	Sagging x 10^8 Nmm
100	0.5	-0.5
200	1.0	-1.0
300	1.5	-1.5
etc.	etc.	etc.

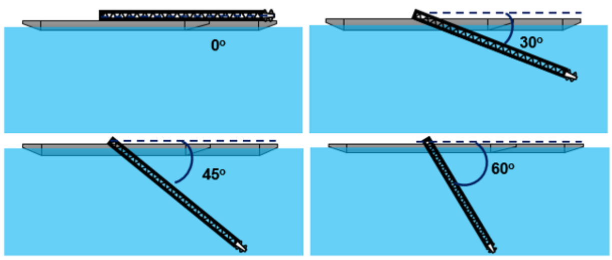

Figure 15. Ladder tilt angle variation

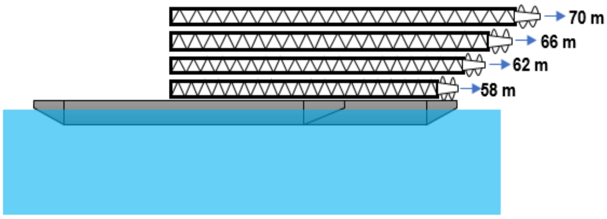

Figure 16. Ladder length variation

3.3. Ladder Length Variation

In this condition, each angle variation such as in the 42 ladder length is varied starting from the initial length of the ladder, namely 58 meters, 62 meters, 66 meters and 70 meters, each length increase is followed by angle variations as shown in Fig. 16.

After calculating the load, then the ladder strength analysis is carried out by looking at the structural response, namely changes in the shape of the ladder structure or shifts and stresses due to loads acting on the ladder such as pipe loads, cutter loads and torque moments due to cutter torque looking at the review points on ladder models.

3.4. Ladder Structure Analysis

a. Analysis of Ladder Structure due to Pipe Load, Cutter Load, and Cutter Torque

Some parts of the modeled structure will experience displacement (shift) when a load acts on it. The ladder model will be tested by giving each load that works on the ladder such as the shift in Fig. 17 due to cutter load, Fig. 18 due to pipe load and Fig. 19 cutter torque.

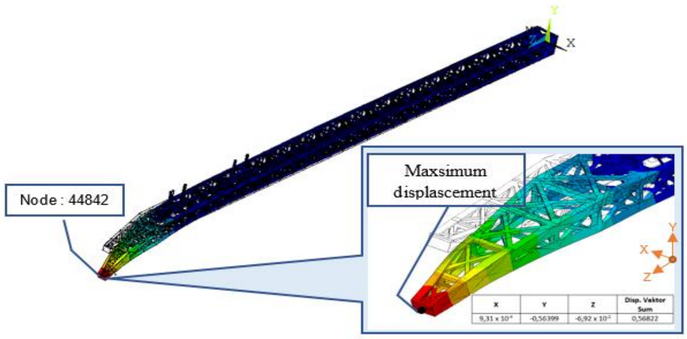

Figure 17. Displacement of x, y and z directions with a model length of 70 meters due to cutter load

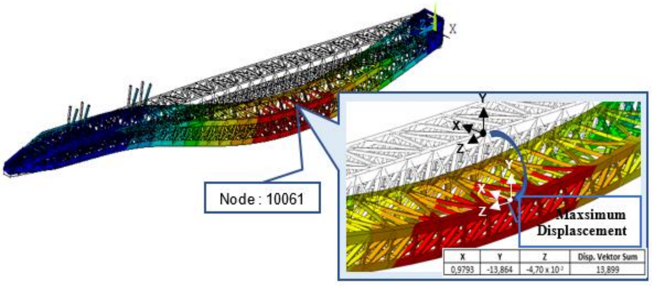

Figure 18. Displacement of x, y and z directions with a model length of 70 meters due to pipe load

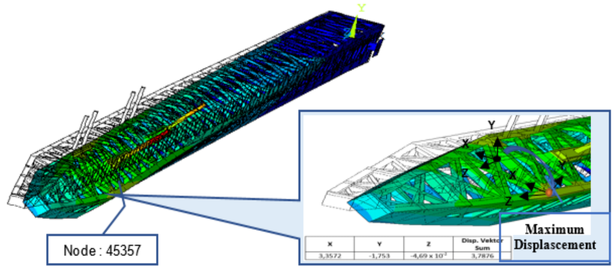

Figure 19. Displacement of x, y and z axes with a model length of 70 meters due to torsional moment

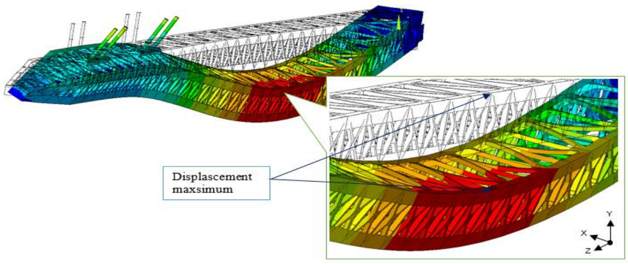

Figure 20. Displacement of x, y and z axes with a model length of 70 meters for all loads

Of the three load experiments, the maximum shift due to the pipe load that occurs in the column along the 42 meters from the shaft ladder is 13.86 mm, while the cutter load shifts 0.57 mm and the cutter torque shifts 3.79 mm. and if the load works simultaneously can be seen in Fig. 20.

Maximum displacement for all directions x, y and z is 14.29 mm for a model length of 70 meters with a shift value in the x direction is 2.22 mm for the y direction is 14.19 mm and the z direction is 0.38 x 10^{-1} mm. Thus the largest displacement occurs in the y direction of 14.19 mm.

Each ladder length is given the same load starting from 58 meters, 62 meters, 66 meters and 70 meters with each increase in ladder length varying the angle starting from the angle of 0º, 30º, 45º, and 60º. The deflection results show that at a ladder length of 58 m for an angle of 0º of 5.06 mm while at an angle of 60o with the same ladder length it has a deflection value of 2.65 mm. For a ladder length of 70 meters with an angle of 0º has a deflection value of 14.28 mm and an angle of 60º has a deflection value of 7.28 mm as shown in Fig. 21.

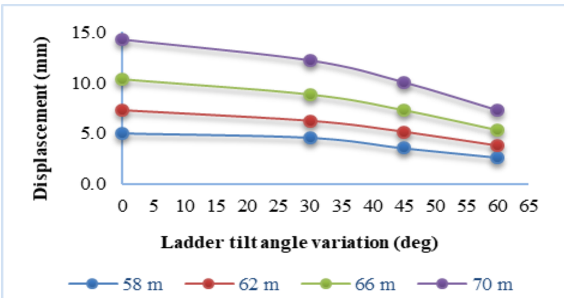

Figure 21. Curve of variation of ladder angle with displacement at each increase in ladder length

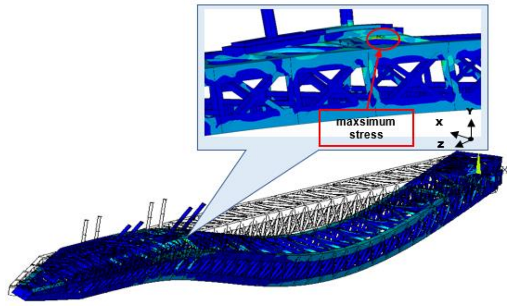

Figure 22. Behavior and distribution of working stress on ladder construction with a model length of 70 meters

Based on Fig. 21 The longer the ladder, the greater the displacement value with an average percentage increase of 29.24% from the initial shift and the greater the slope angle of the ladder the smaller the shift with an average reduction of 19.9%from the initial displacement.

Stress is the magnitude of the force exerted by the molecules on the cross-sectional area as shown in Fig. 22.

Based on Fig. 22 it can be seen that the maximum stress occurs in the strut area of the pulley foundation which functions to move up and down the ladder. Strut withstands the greatest load so that it gets a maximum stress of 56.88 N/mm2. Each length of the ladder is given the same load, starting from the length of the ladder 58 meters, 62 meters, 66 meters and 70 meters with each increase in the length of the ladder varying the angle starting from the angle of 0°, 30°, 45°, and 60° so that the stress results can be seen. in Fig. 23.

Based on Fig. 23 The longer the ladder, the greater the stress value with an average percentage increase of 29.24% from the initial stress and the greater the slope angle of the stress ladder decreases with an average reduction of 19.9% from the initial stress.

b. Analysis of Ladder Structure in the Pulley Area

Due to pipe load, cutter load and cutter torque, based on the results of the analysis, the maximum stress occurs in the pulley area. To facilitate the identification of each component of the construction as shown in Fig. 24.

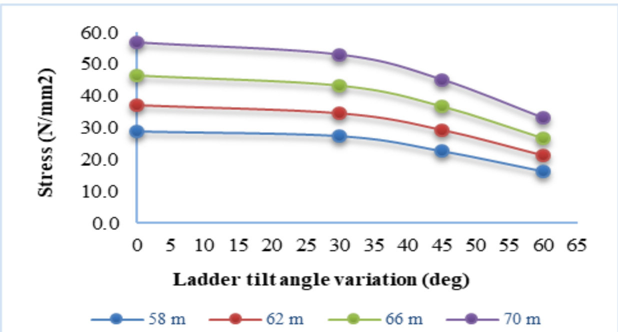

Figure 23. Variation curve of ladder angle with stress (von mises stress) at each increase in ladder length

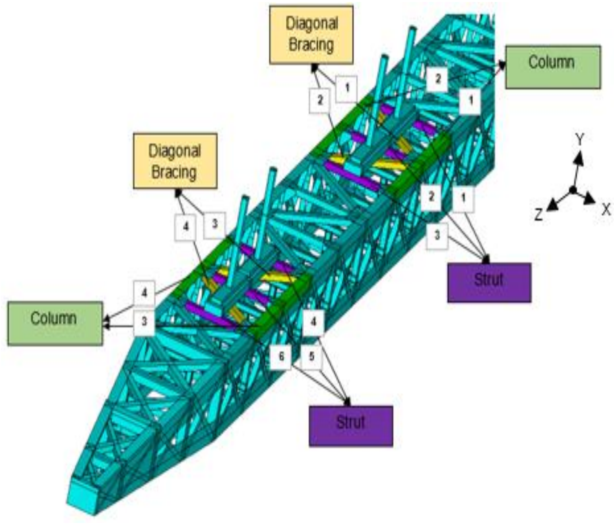

Figure 24. Components of the ladder structure to be analyzed

Based on Fig. 24, it can be seen the division of structural components in the pulley foundation area which consists of 6 units of strut components, 4 units of diagonal Brace components and 4 units of column components. After the analysis, it is divided into two areas as shown in Fig. 25.

Based on Fig. 25 the maximum stress occurs at strut number 1. The strut component has the maximum maximum stress right at strut 1 which has a major role in holding the rope due to the pipe load and the ladder construction along 49 meters.

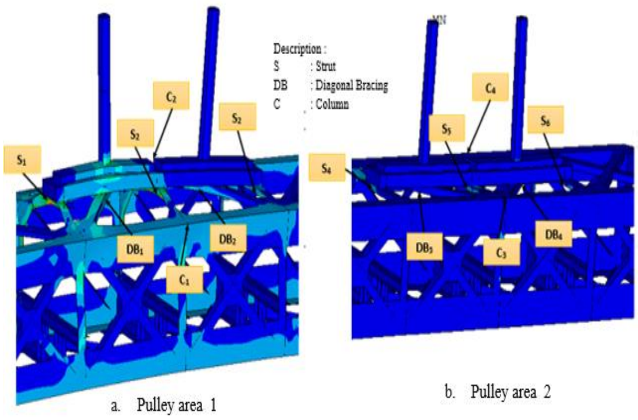

Figure 25. Behavior and distribution of working stress on ladder structure (pulley 1) foundation area, (pulley 2) foundation area

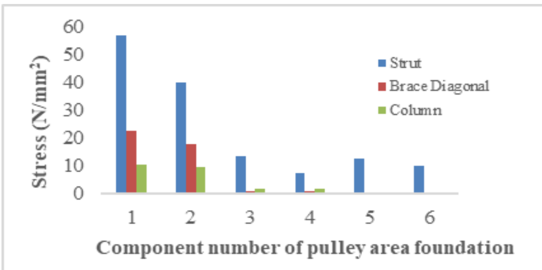

Figure 26. Relationship between stress and structural components of the pulley foundation area

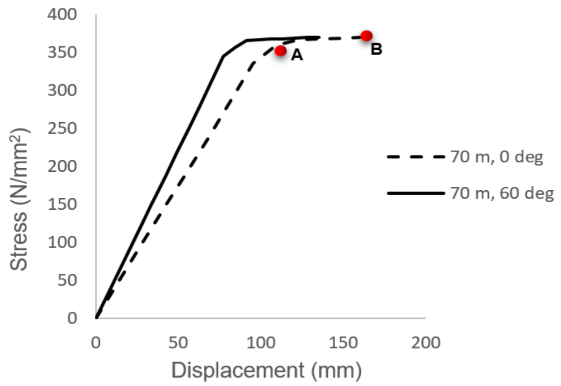

Figure 27. The curve of the relationship between stress and displacement

Based on Fig. 26 the maximum stress occurs in strut number 1. The strut component has the maximum stress that is right at strut number 1 which has a big role in holding the rope due to the pipe load and the 49 meter long ladder construction.

c. *Ultimate Strength*

Ultimate strength is the stress at the highest level that a test object can withstand before it breaks. In the experiment the model will be tested by increasing the load variation until the model collapses. With variations in the increase in the load that works on the ladder including the pipe load, cutter load and cutter torque, there is a maximum stress on strut 1. So each load is varied every 100% increase from the initial load until strut number 1 collapses so that from the variation of the load the limit strength is obtained. like in Fig. 27.

From the results of the experiment, at an angle of o degree ladder the strut will collapse 60 degrees and at an angle of 60 degrees it will shift 130.6 mm. so from Fig. 27 it can be seen that the greater the slope angle of the ladder, the smaller the displacement value.

The longitudinal strength of the ladder was analyzed using the Multiple Point Constraint (MPC) method with variations in vertical bending moment. The end of the ladder shaft is on the reins of the x, y and z axes. Then the end of the ladder where the cutter is on the reins in the x and y directions, all axes of rotation are freed. one end is given a moment. Then we will review the maximum displacement that occurs in the model in the hongging and sagging conditions as shown in Fig. 28.

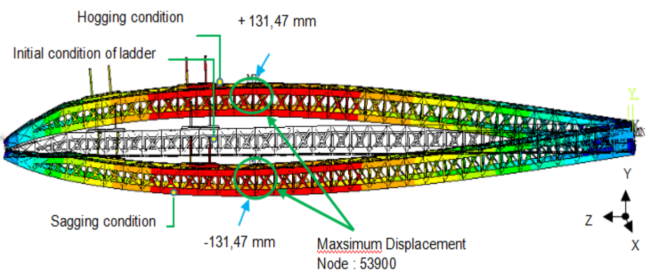

Figure 28. Displacement the limit strength a ladder with a length of 70 meters and an angle of 0 degrees on the y-axis due to hogging and sagging

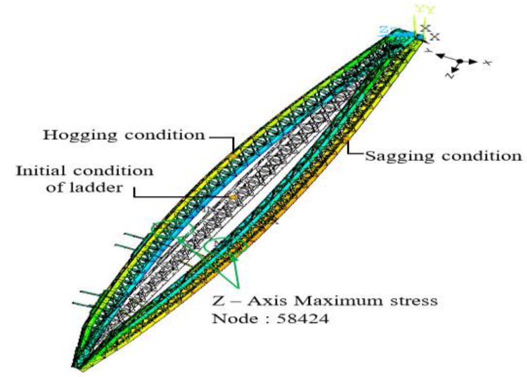

Figure 29. Behavior and distribution of limiting stress on a ladder length of 70 meters and a slope angle of 60 degrees the z-axis due to hogging and sagging

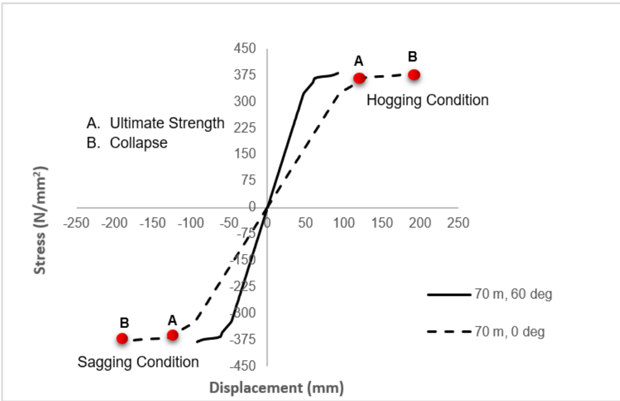

Figure 30. Curve of the relationship between stress and bending moment variations in hogging and sagging conditions

Based on Fig. 28 The maximum displacement at an angle of 0 degrees occurs in the column with a distance of 42 meters from the end of the ladder shaft which will collapse when it receives a moment of 2.89 x 10^9 Nmm with a maximum shift of 131.73 mm. Stress generated at an angle of 60 degrees can be seen in Figure 29.

Based on Fig. 29 The maximum stress at an angle of 60 degrees occurs at the end of the ladder which is restrained and will collapse when it receives a moment of 1.45 x 10^9 Nmm with a maximum shift of 66.17 mm from the initial position of the ladder before it is loaded.

Based on Fig. 30 it can be seen at the ladder tilt angle of 0 degrees for hogging and sagging conditions the limit of the bending moment that can be endured is 2.91 x 10^9 Nmm while at a slope angle of 60 degrees the limit of the bending moment that can be endured is 5.82 x 10^9 Nmm. so that for the same ladder length the greater the angle of inclination is inversely proportional to the value of the stress and displacement.

4. Conclusion

Based on the results the analysis the load acting on the ladder, namely pipe load, cutter load and cutter torque. The longer the ladder is directly proportional to the stress and displacement values produced with an average increase of 24.8% from the initial value and the greater the slope angle of the ladder is inversely proportional to the stress and displacement values produced with an average decrease of 16.6% from the initial value. At an angle of 0 degrees the strut ladder will collapse when shifted 160.2 mm. 60 degree angle of collapse when receiving a displacement of 130.36 mm. Based on the results of the analysis of the strength of the longitudinal ladder structure in the conditions of hogging and sagging, a distance of 42 meters from the ladder shaft experienced a maximum shift in the column of 131.73 mm from the initial position before being loaded. While at an angle of 60 degrees it will collapse when receiving a 0.49% decrease from the initial shift of the 0 degree angle.

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