Maritime Technology and Society
Vol. 4(3): 180-190, October 2025
https://doi.org/10.62012/mp.vi.45323

Regular Research Article

Finite Element Analysis of the Gravity Davit Structure on MV. Sultan Hasanuddin with Variations Lifeboat Load Capacity

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Abstract: The purpose of this study is to measure the maximum support capacity of the Davit structure on MV. Sultan Hasanuddin uses variations in lifeboat load capacity. Davits on ships function as tools used to raise or lower lifeboats on board. The method used in this study is a quantitative method employing the Finite Element Analysis (FEA) technique to determine the ultimate stress and maximum deformation occurring in the Davit structure of the MV. Sultan Hasanuddin due to loading effects. Based on simulation results with six variations of passenger loading, the maximum stress experienced by the Davit (Davit) of the MV. Sultan Hasanuddin was on the suspension block, specifically on the davit chain. It was found that the maximum passenger weight limit on the lifeboat that does not exceed the BKI allowable stress is 4,363 kg, or an additional load of 35% of the total passenger weight, with a maximum gravitational force acting on the lifeboat of 74,441 N on the davit structure.

Keywords: Davit; MV. Sultan Hasanuddin; Finite Element Analysis; ultimate stress.

1. Introduction

Maritime safety in the maritime transportation system plays a very important role and must be taken seriously. The International Maritime Organization (IMO) regulation, SOLAS-74, was amended in 2006 with additional provisions regarding the obligation to place crew members in lifeboats during lifeboat lowering drills. This amendment has the potential to create a genuine emergency during lifeboat lowering exercises or simulations. If the design and construction of the lifeboat's motorized hoisting system are inaccurate, it could lead to failure in the evacuation process. The accuracy of load and force or moment calculations must accurately represent the actual conditions of the lifeboat and its deployment and lowering mechanisms [1]. The IMO's General Regulations on Lifeboats include important provisions on construction, capacity, access, buoyancy, stability, propulsion, and deployment. The lifeboat's construction must be strong enough to withstand the load during launching and hoisting, without any deflection that could interfere with the launching process. The lifeboat is one of the lifesaving equipment items that must be included in the shipbuilding requirements, including its construction, mechanical systems, and equipment for lowering and hoisting the lifeboat [2]. The general principle governing the provisions regarding lifeboats, life rafts, and floating devices on this vessel is that all must be in a state of readiness for use in an emergency [3]. All lifeboats must be constructed suitably and must have shape and proportions such that they have sufficient stability when fully loaded

Received 2025-06-30; Accepted 2025-07-24; Published 2025-10-08

with authorized persons and their equipment. All lifeboats must be able to maintain positive stability when at sea while fully loaded with authorized persons and their equipment.

Davits function as tools used to raise or lower lifeboats on ships. Davits are often not maximized in procurement planning and use, resulting in suboptimal support capabilities [4]. Davits on ships function as tools used to raise or lower lifeboats on board. Davits must operate effectively and meet structural strength requirements when lowering lifeboats fully loaded under various operational conditions [5]. Over time, davit materials may corrode, reducing their operational efficiency [6].

Moreover, the maximum load can cause the lifeboat to fail to be lowered, thereby endangering the safety of passengers and crew. Since most shipyards do not manufacture davits and lifeboats themselves but purchase them from manufacturers or receive them from shipowners and only install them on the ship's deck, it is necessary to verify the structural integrity by reviewing the specifications provided by the manufacturer. If required, modifications can be made to the existing structure, and adjustments may also be needed due to requests for changes in lifeboat capacity.

Figure 1. MV. Sultan Hasanuddin with Davits and Lifeboats

Figure 1 shows that KL Sultan Hasanuddin is one of six 1200 Gross Tonage cadet training ships built by the Ministry of Transportation to support activities and improve the training capabilities of maritime academy cadets or prospective Indonesian sailors. However, MV Sultan Hasanuddin currently operates as a public passenger transport vessel in the islands and ports of South Sulawesi. The MV Sultan Hasanuddin is equipped with two lifeboats, each with its davit. Given that the MV Sultan Hasanuddin is now primarily used for passenger transport rather than as a training vessel, it is necessary to research to determine the maximum load-bearing capacity of the davit structure on the MV Sultan Hasanuddin using variations in lifeboat load capacity.

2. Methods

A davit is one of several devices, such as a crane, used on ships to support, raise, and lower equipment such as boats and anchors, as shown in Figure 2. Davit systems are most often used to lower emergency lifeboats to the departure level for boarding. The lifeboat davit has a fold (now made of wire, historically made of Manila rope) used to lower the lifeboat into the water. The davit can also be used as a safety device to rescue people who have fallen from the ship into the water. To design a 3D davit, a precise 2D initial design is required. Based on data obtained from field observations in the form of blueprints and the actual condition of the ship's davit, a 2D davit design was created as shown in Figure 2. Subsequently, 3D davit design data was created as a sample for analysis. Figure 2 shows the 3D design of the davit with the percentage of the structure and construction of the 3D davit model, including the frame, davit arm (cradle), davit arm stops handle, suspension link, and suspension block. In this study, the focus is on the structure of the davit, so other parts of the davit are not depicted, such as the platform, winch, pulley mechanism, remote control wire, boat fall wire, and lifeboat. Figure 2 shows the results of the three-dimensional (3D) solid modeling of the Davit on the Sultan Hasanuddin ship using 3D design software. The positioning of the coordinates of each reinforcing structure (adjacent) must be aligned so that contact between the structures can be defined. This is important to consider when transferring and analyzing 3D data of the Pinisi ship into the Finite Element Analyst (FEA) software to obtain relevant finite element calculation results.

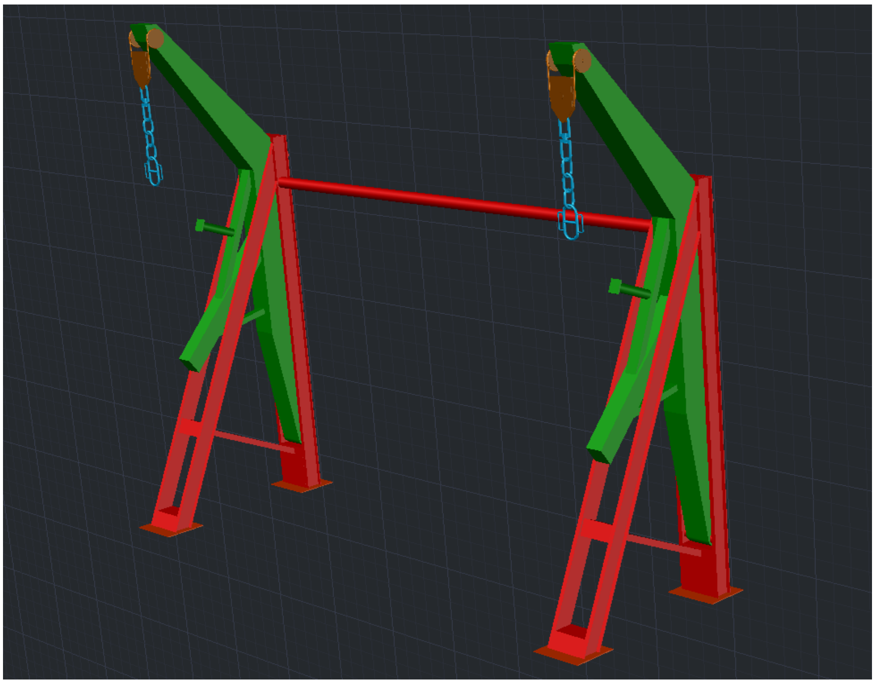

Figure 2. Results of 3D modeling of the Davit structure

The analysis of the Davit 3D numerical model in lifeboat load variation simulations was performed using the Finite Element Method with Explicit Dynamics sub-analysis. Explicit dynamics analysis can analyze physical changes in elements over shorter time variables (short-duration) than Static Structural analysis, enabling the analysis of complex structures and changes in body interactions. Explicit dynamic analysis can analyze loads that cause significant geometric deformation [7]. In analyzing complex ship structures and significant geometric changes during ship launching, explicit dynamics analysis can be used. Dynamic analysis can be performed using either implicit or explicit solution methods. However, implicit analysis becomes unstable when there are significant changes to the model and time, so explicit dynamic analysis becomes the solution to the problem [8]. The basic structural analysis equations describing the response of the original structure can be seen in the following equations:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(t)\} \qquad (3)$$

Where M is the mass matrix (kg), C is the damping matrix (N s/m), K is the stiffness matrix (N/m), and F is the external force vector concerning time t. To ensure that the Explicit Dynamics analysis remains stable, a time step size constraint is applied using the Courant-Friedrichs-Lewy CFL condition equation [9]. Validating the 3D model is a very important process to align real-world conditions with the structure being analyzed to obtain accurate results [10], [11]. Validating the 3D davit structure model is a crucial step in this research, ensuring that the digital model accurately represents the physical davit structure at KL Sultan Hasanuddin. This process cannot be overlooked because the accuracy of the simulation results depends heavily on how well the model reflects reality. Validation may involve various methods, such as comparing key dimensions on the model with previous field measurement results. Additionally, if possible, comparisons with the initial design data or technical specifications of the davit can also be part of this validation process. In addition to validating the three-dimensional model's dimensional parameters, it is necessary to validate the structural weight comparison [12]. To determine the consistency between the Davit model's geometric dimensions and the actual dimensions on-site, the model is validated by comparing the calculated and estimated weights of the Davit. The structural weight of the davit specified in the technical specifications is 3,800 kg per set, while the 3D simulation sample of the davit weighs 3,627 kg. There is a difference of approximately 173 kg because the model does not include the platform, winch, pulley mechanism, remote control wire, and boat fall wire.

3. Results

In the simulation stage of this study, five load variations were used to obtain the limit load, which is the maximum capacity of the Davit MV. Sultan Hasanuddin. At load 1 (100% load), a load of 6376 kg or 62544 N was applied to the Davit, consisting of the weight of the lifeboat, lifeboat equipment, and 45 passengers, as detailed in Table 1 and illustrated in Figure 3.

Table 1. Load Variation 1 (100% load)

Load	Weight (Kg)	Quantity	Total (Kg)
Lifeboat	2.981	1	2.981
Equipment	245	1	245
Persons	70	45	3.150
			6.376

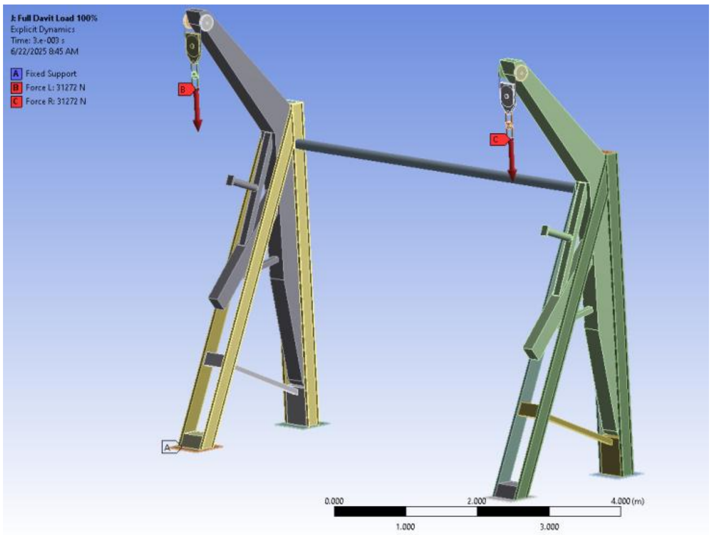

Figure 3. Load Setup 1 (100% load) on Davit

Total deformation of a davit refers to the change in shape or physical displacement experienced by the structure when subjected to a load. Each time a lifeboat is suspended or lifted, the gravitational and dynamic forces acting on the davit cause the material to stretch, bend, or twist slightly. Although in many cases this deformation may not be visible to the naked eye, deformation calculations are crucial to ensure that the davit remains within safe tolerance limits and functions as intended. Excessive deformation not only indicates structural weakness but also has the potential to disrupt the lifting mechanism or even cause the davit to fail. Total deformation analysis provides an overview of how far each point on the davit structure moves from its original position. This data is invaluable for evaluating the rigidity of the davit and ensuring that the displacement does not hinder operations or pose safety risks. For example, excessive deformation of the davit arm could cause the lifeboat to sway uncontrollably or even touch the ship's hull, potentially damaging both. Figures 4 and 5 show the total deformation occurring on the davit when subjected to a 100% load, with the largest deformation occurring on the davit's suspension block connected to the wire winch, with a deformation value of 0.0066 m or 6.6 mm.

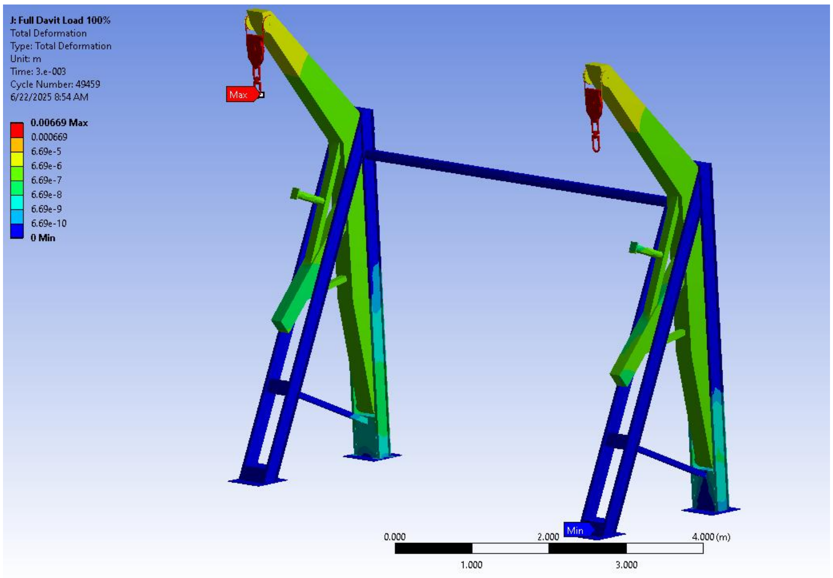

Figure 4. Total deformation on the Davit with 100% load

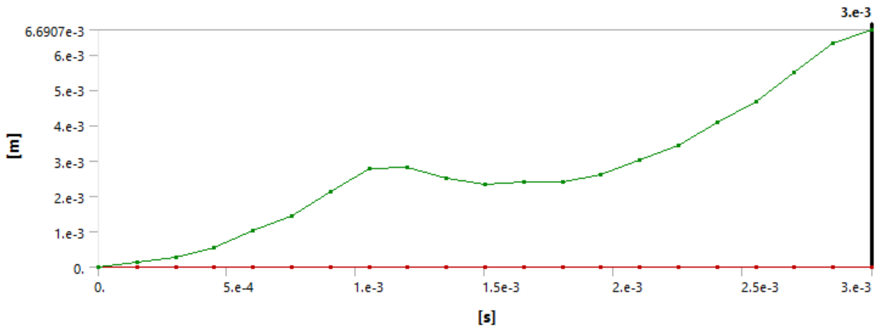

Figure 5. Graph of total deformation against simulation time on Davit with 100% load

Strain on a davit is a measure of the relative deformation of a material, or how much the material stretches or shortens per unit of its original length, in response to the stress acting on it. Unlike total deformation, which measures absolute displacement, strain provides insight into the internal dimensional changes of a material at the microscopic level. There are two main types of strain: normal strain, which occurs when the material stretches or shortens due to tensile or compressive stress, and shear strain, which occurs due to angular distortion between two lines that were originally perpendicular within the material. The results of the davit simulation can be seen in Figure 6, which shows the location of strain on the davit structure when subjected to a 100% load. The maximum tensile-compressive strain was found in the davit's suspension block, specifically in the chain, with a maximum tensile strain of 0.0018 m or 1.8 mm and a maximum compressive strain of 1.3 mm, as shown in the tensile-compressive strain versus simulation time graph in Figure 7.

Understanding the strain distribution throughout the davit structure is critical because strain is directly proportional to stress within the elastic limit of the material, following Hooke's Law. This means that areas with high strain will also have high stress, indicating potential critical areas that are susceptible to failure. Strain analysis enables the prediction of when the material will reach its plastic limit (the point at which deformation becomes permanent) or even the point of fracture. By comparing the simulated strain with the allowable strain limit for the davit material, it can be ensured that the structure is not only safe from fracture but also maintains its functional integrity without suffering detrimental permanent deformation.

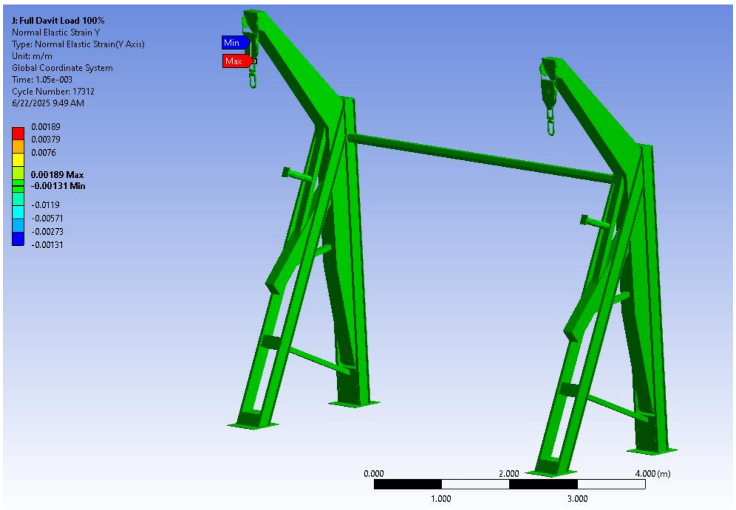

Figure 6. Strain on Davit with 100% Load

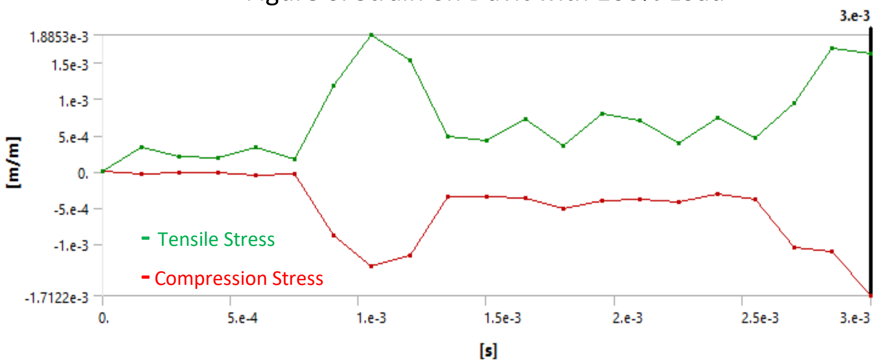

Figure 7. Graph of strain versus simulation time on a davit with 100% load

Stress on a davit is a crucial parameter in structural analysis that describes the intensity of internal forces acting per unit area of the material cross-section. When a davit supports a load, such as a lifeboat carrying passengers, these external forces are distributed throughout the structure, causing the material particles to pull or push against each other. There are several types of stress relevant to a davit, including normal stress (tensile or compressive) occurring perpendicular to the cross-section, and shear stress occurring parallel to the cross-section. Understanding the distribution and magnitude of these stresses is essential for assessing structural integrity and preventing material failure.

Stress analysis on davits allows for the identification of critical areas experiencing high stress concentrations, namely the parts of the davit that are most susceptible to plastic deformation or fracture. For example, connection points, sharp cross-sectional changes, or areas where loads are applied directly often become locations with peak stresses. The results of the davit simulation can be seen in Figure 8, which shows the stress locations on the davit structure when subjected to a 100% load. The maximum tensile-compressive stress occurs at the davit suspension block, specifically on the chain, with a maximum tensile stress of 347 MPa and a maximum compressive stress of 309 MPa, as shown in the tensile-compressive stress versus simulation time graph in Figure 9.

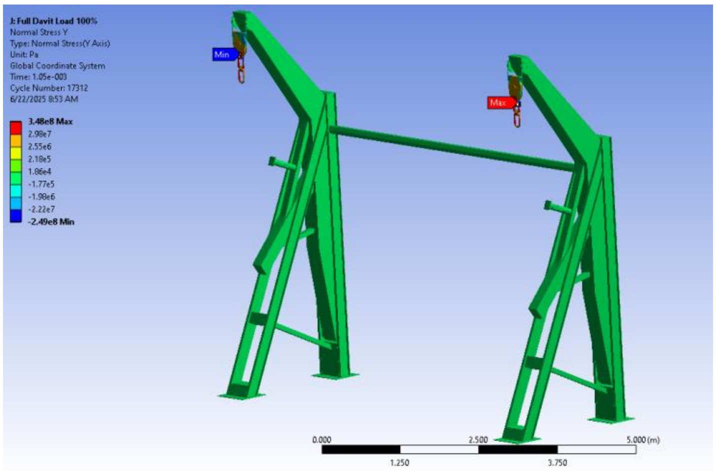

Figure 8. Tensile-Compressive Stress on Davit with 100% Load

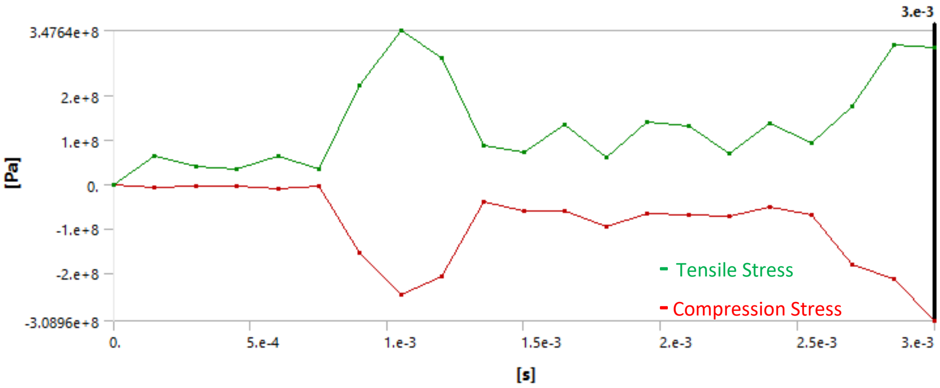

Figure 9. Graph of Tensile-Compression Stress vs. Simulation Time Davit with 100% Load

This study focuses on load variations at maximum stress on the Davit KL Sultan Hasanuddin with maximum stress limits permitted by the Indonesian Register of Shipping (BKI). It has been discussed previously that maximum tensile stress occurs on the Davit suspension block, specifically on the chain. Further load variations will show a graph of the stress occurring on the davit.

Table 2 shows the third load variation with an additional passenger load capacity of 15% or 7 passengers with a total passenger weight of 3,623 kg, where the total weight of the lifeboat is 6,848 kg or with a weight force of 67,179 Newton. Based on these load conditions, a simulation was conducted, resulting in a maximum stress of 398 MPa at the Davit suspension block, as shown in Figure 10.

Table 2. Load Variation 3 (115% load)

Load	Weight (Kg)	Quantity	Total (Kg)
Lifeboat	2981	1	2981
Equipment	244,5	1	245
Persons	70	52	3623
			6848

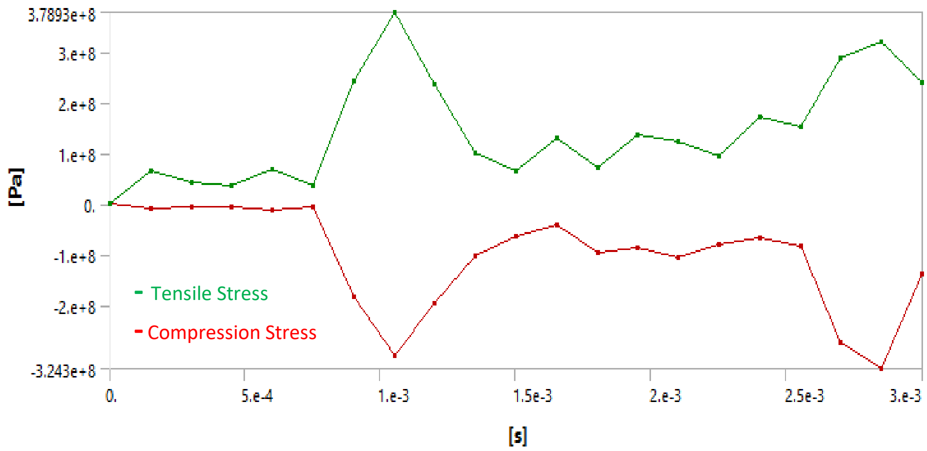

Figure 10. Graph of Tensile-Compression Stress vs. Simulation Time Davit with 115% Load

Table 3 shows the fourth load variation with an additional passenger load capacity of 25% or 11 passengers with a total passenger weight of 3,938 kg, where the total weight of the lifeboat is 7,163 kg or with a weight force of 70,269 N. Based on these load conditions, a simulation was conducted, resulting in a maximum stress of 370 MPa at the Davit suspension block, as shown in Figure 11.

Table 3. Load Variation 4 (125% load)

Load	Weight (Kg)	Quantity	Total (Kg)
Lifeboat	2981	1	2981
Equipment	244,5	1	245
Persons	70	56	3938
			7163

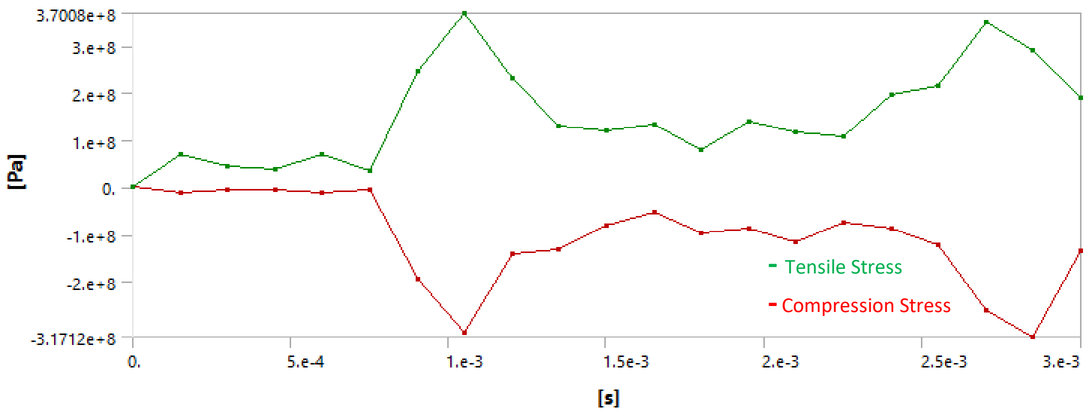

Figure 11. Graph of Tensile-Compression Stress vs. Simulation Time Davit with 125% Load

Table 4 shows the fifth load variation with an increase in passenger load capacity of 35% or 17 passengers with a total passenger weight of 4,363 kg, where the total weight of the lifeboat is 7,588 kg or with a weight force of 74,441 N.

Table 4. Load Variation 5 (135% load)

Load	Weight (Kg)	Quantity	Total (Kg)
Lifeboat	2981	1	2981
Equipment	244,5	1	245
Persons	70	62	4363
			7588

Based on these load conditions, a simulation was conducted, resulting in a maximum stress of 400 MPa at the Davit suspension block, as shown in Figure 12. The allowable stress for the anchor chain according to the Indonesian Classification Bureau (BKI) is 400 MPa [13]. Allowable stress is the maximum stress limit permitted on a material or component, in this case, the anchor chain, to prevent permanent damage. This stress is the maximum limit that must not be exceeded to ensure the chain remains safe during use.

Exceeding the allowable stress can cause the anchor chain to break, potentially leading to serious accidents.

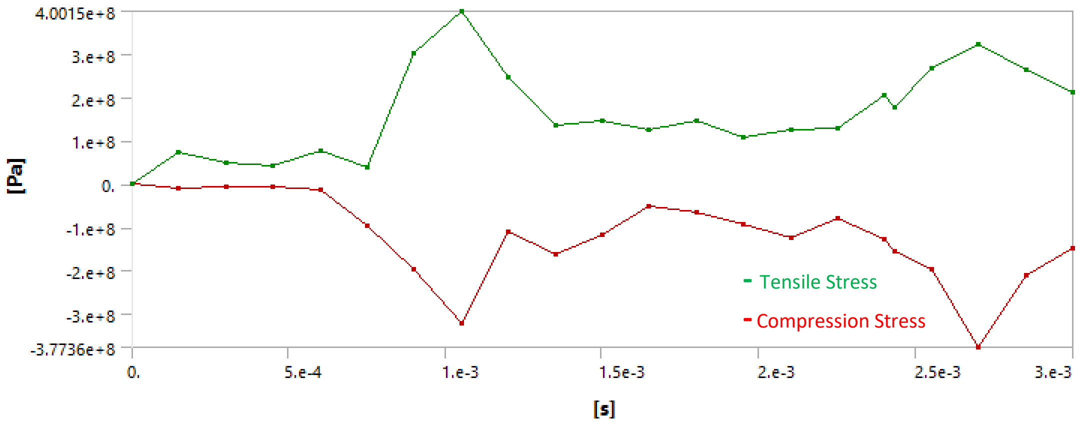

Figure 12. Graph of Tensile-Compression Stress vs. Simulation Time Davit with 135% Load

Table 5 shows the fifth load variation with an increase in passenger load capacity of 45% or 20 passengers with a total passenger weight of 4,568 kg, where the total weight of the lifeboat is 7,793 kg or with a weight force of 76,449 N. Based on these load conditions, a simulation was conducted, resulting in a maximum stress of 406 MPa at the Davit suspension block, as shown in Figure 13. At stress levels exceeding 35% of the load, the stress exceeds the recommended allowable stress specified by BKI.

Table 5. Load Variation 6 (145% load)

Load	Weight (Kg)	Quantity	Total (Kg)
Lifeboat	2981	1	2981
Equipment	244,5	1	245
Persons	70	62	4363
			7588

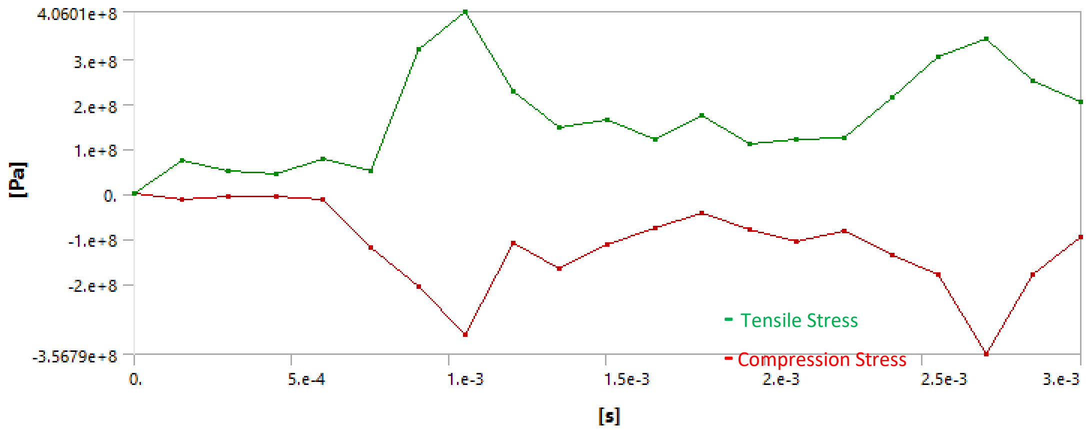

Figure 13. Graph of Tensile-Compression Stress vs. Simulation Time Davit with 145% Load

Figure 14 shows the curve of the relationship between the load variation on the lifeboat and the maximum stress experienced by the davit, as well as the permissible stress limit recommended by the Ship Classification Bureau (BKI) and the maximum load (Max Load) stated in the technical specifications of the MV. Sultan Hasanuddin davit. Based on the graph, it is determined that the maximum passenger weight on the davit that does not exceed the BKI permissible stress limit is 4,363 kg, or an additional load of 35% of the total passenger weight, with the maximum weight force acting on the lifeboat being 74,441 N. The maximum weight force limit from the simulation, when compared to the maximum weight force permitted in the davit's technical specifications of 71,000 N, has a difference of up to 8% of the load or 3,441 N. The margin of error with a deviation of 8% allows for differences in the maximum permissible load standards in regulatory classes, as the country where the davit and lifeboat are ordered may use standards other than BKI, such as CCS (China Classification Society) or other regulatory standards. Based on the curve graph in Figure 14, the coefficient of determination (R^2) is 0.8 (80%), indicating that the model has excellent capability in explaining the variation of the dependent variable. Specifically, the total variability or change observed in the dependent variable can be explained or predicted by the independent variables included in the regression model.

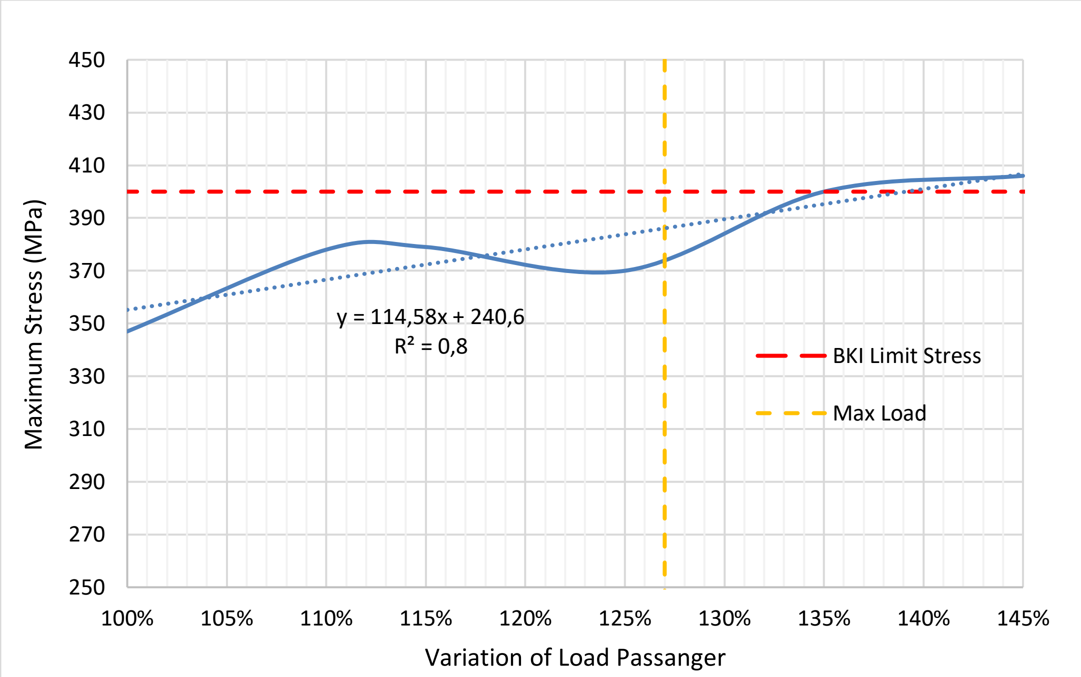

Figure 14. Graph of Davit Load Variation versus Stress

4. Discussion

The relationship between load variation and stress in davit structures is fundamental to technical analysis. In general, the greater the load acting on a structure, the higher the internal stress experienced by the material. This is because stress is defined as force per unit area, so an increase in force (load) will directly increase the intensity of pressure or tension felt by each cross-section of the material. In the context of a davit, load variations can arise from various scenarios, such as a lifeboat with full passenger capacity, additional cargo, or even dynamic loads caused by the ship's movement at sea. Each of these loading scenarios will result in different stress distribution patterns across the davit components.

Understanding this relationship is crucial because stress is the primary indicator of structural safety and reliability. By varying the load in simulations, we can identify critical loading scenarios that produce the highest stresses on the davit. Areas experiencing peak stresses under certain loads are the most vulnerable points for failure. Therefore, it is essential to ensure that the maximum stresses resulting from load variations never exceed the material's allowable strength limits as per safety standards.

5. Conclusions

Based on the simulation results, it was found that the maximum passenger weight limit on the lifeboat that does not exceed the BKI permit tension is 4,363 kg, or with an additional load of 35% of the total passenger weight, with a maximum weight force acting on the lifeboat of 74,441 N against the Davit. Based on the discussion, the maximum stress experienced by the davit of MV. Sultan Hasanuddin is located at the suspension block, specifically on the davit chain.

Based on the simulation results and discussion, it is recommended that regular Davit Drill Tests be conducted because material age and corrosion factors can reduce the strength of the davit material in withstanding lifeboat stress and load. Based on the survey conducted, it was observed that the chain on the davit suspension block was poorly maintained, as evidenced by corrosion (rust). The rust is likely due to stress concentration occurring on the chain, necessitating special maintenance such as coating or, if necessary, replacing the chain with a new one.

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